HABITAT RELATIONSHIPS OF SEVEN BREEDING BIRD SPECIES IN THE LEON RIVER WATERSHED INVESTIGATED AT LOCAL SCALES

A Thesis

by

EDWIN ALFREDO JUAREZ BERRIOS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2004

Major Subject: Wildlife and Fisheries Sciences

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Approved as to style and content by:

R. Neal Wilkins (Co-Chair of Committee)	Sallie Hejl (Co-Chair of Committee)
Fred Smeins (Member)	Robert D. Brown (Head of Department)

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ABSTRACT

Habitat Relationships of Seven Breeding Bird Species in the Leon River Watershed Investigated at Local Scales. (December 2004)

Edwin Alfredo Juarez Berrios, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. R. Neal Wilkins
Dr. Sallie J. Hejl

Over the past 100–150 years Texas rangelands have dramatically changed from native open savannahs to dense woodlands. On the Edwards plateau, a major management concern is the increasing encroachment of Ashe juniper (*Juniperus ashei*). Preceding an anticipated brush management program, I investigated the presence, co-occurrence, and habitat relationships of 7 breeding bird species in the Leon River Watershed in central Texas, USA: black-capped vireo (*Vireo atricapillus*), golden-cheeked warbler (*Dendroica chrysoparia*), northern bobwhite (*Colinus virginianus*), white-eyed vireo (*Vireo griseus*), Bell's vireo (*Vireo bellii*), painted bunting (*Passerina ciris*), and brown-headed cowbird (*Molothrus ater*). Vegetation characteristics were compared between sites occupied by each species and unoccupied sites using univariate analysis. Models for predicting species site occupancy were developed (using logistic regression) based on habitat characteristics correlated with the presence of each species. Two species of special concern, the endangered black-capped vireo and golden-cheeked warbler occupied 5.6% of sites and 13.8% of sites respectively, while the brood parasite brown-headed cowbird was the most widespread, occupying 86.8% of sites. Species co-occurrence patterns revealed significant associations between the golden-cheeked warbler and each of 5 other species. For most species, variables included in habitat models could be explained by knowledge of species known habitat associations. For example, the black-capped vireo was positively associated with increasing low-growing (<1.5 m) hardwood cover and with Low Stony Hill ecological sites. The golden-cheeked warbler was positively associated with increasing density of larger juniper trees, increasing variability in vertical vegetation structure, and decreasing midstory canopy of deciduous nonoaks (e.g., cedar elm [*Ulmus crasifolia*]). It also preferred Low Stony Hill and Steep Adobe ecological sites. Site occupancy seemed to be driven by variables that describe overall vegetation structure. In particular, cover of low-growing non-juniper vegetation and juniper tree density appeared to be important in determining site occupancy for several species. Although the models constructed were not very robust, resource managers can still benefit from such models because they provide a preliminary examination of important controlling variables. Managing rangelands to maintain or restore a mosaic of juniper patches and open shrublands are likely to help meet the habitat requirements of these bird communities.

DEDICATION

This thesis is dedicated to my parents, Jose Juarez and Maria Berrios. Their vision and courage to immigrate to these United States provided my siblings and me with the opportunity to strive for a better future.

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I would like to thank the Hispanic Leadership Program in Agriculture and Natural Resources whose stated goal is to promote professional development and to enhance research and policy issues related to Hispanics and agriculture and natural resources. Besides providing me with financial support, this U.S. Department of Agriculture-funded program helped me develop my leadership skills, and expand my understanding of policy analysis. Thanks to all the graduate students who helped with field work, including Frank Holland, Jenny Cearley, Lisa James, and Courtney Hale, and thanks also to Jason Jones who helped me numerous times with GIS issues. Thanks to all the landowners for allowing us access to their ranches. To my committee Sallie Hejl, Neal Wilkins, and Fred Smeins, thank you for your support and guidance. Thanks to Neal Wilkins for helping me stay on schedule and Sallie Hejl for always lending an ear to hear my occasional frustrations. Thank you to my parents, Jose Juarez and Maria Berrios for always supporting my academic endeavors.

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INTRODUCTION

A dramatic change that has occurred on Texas rangelands over the past 100–150 years has been the conversion of native open savannahs to dense woodlands (Smeins et al. 1997). On the Edwards Plateau, a major management concern is the increasing encroachment of Ashe juniper across rangelands, because of its negative impact on the hydrologic cycle (Thurrow and Hester 1997). Because of water shortages in the state of Texas, brush control (i.e. juniper removal) is viewed as a viable method for increasing the amount of water available (Wilcox 2002). Rollins and Armstrong (1997:26) suggest that "vast dense juniper stands are not conducive to either wildlife or livestock management". Instead, a mosaic pattern of brush and open areas is thought to be beneficial for both wildlife and livestock (Rollins and Armstrong 1997, Hamilton 2000, Ball and Taylor 2003). Thus an integrated brush management program may enhance wildlife habitat, and increase water yield and livestock forage (Hamilton 2000). Wildlife species which are likely to benefit from appropriate brush management include game species (Rollins 2000) such as the white-tailed deer (*Odocoileus virginianus*) (Fullbright 1997) and northern bobwhite (Guthery and Rollins 1997) and nongame species such as the black-capped vireo (Grzybowski 1995).

Brush Management

The consideration of landscape-level brush management programs warrants the need to assess how various wildlife species will respond to brush control, because the

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This thesis follows the style and format of the Journal of Wildlife Management.

effects of brush control on wildlife habitat can be positive, negative or neutral, depending on the clearing intensity and subsequent grazing management (Rollins 2000). According to theory, intermediate disturbances caused by brush control may increase species richness and diversity, particularly in ecosystems where natural periodic disturbances such as fires no longer occur (Fullbright 1996). This theory seems to be useful in some cases, for example Rollins (1983) found that a landscape mosaic of cleared and untreated areas of juniper increased bird richness and diversity. Schnepf et al. (1998) suggested that the clearing of juniper enhanced the biodiversity of small mammals. In fact, opening these brushlands is likely to mimic historic landscape patterns. Prior to European settlement, much of the Edwards Plateau was a savanna of juniper patches and open grasslands, which varied depending on the frequency and intensity of fires (Smeins et al. 1997).

Avifaunal Declines

Recent declines in the populations of many land bird species, including Neotropical migrant birds have led researchers to focus on factors affecting populations of these birds (Robbins et al. 1989, Sauer et al. 2003). Partners in Flight (Riley 1996) list several species in central Texas as priorities for conservation. Partners in Flight determine priority status for a species by generating scores that consider overall vulnerability to regional extirpation, major population trends, and local expert opinion (Carter et al. 2000). High priority species in the Edwards Plateau and Oaks and Prairies Physiographic regions (central Texas) include the black-capped vireo, golden-cheeked warbler, northern bobwhite, Bell's vireo, and painted bunting (Partners in Flight 2001*a*).

Population trends of the northern bobwhite, Bell's vireo and painted bunting have shown moderate or significant decreases over the past 30 years (Partners in Flight 2001*b*). Furthermore, threats to suitable breeding conditions for these species are deemed to be moderate or severe. Threats are defined as any extrinsic factors that affect a species survival or reproductive success (Carter et al. 2000). In the Edwards Plateau, threats to bird habitats include forest fragmentation, intensive agricultural practices, and urbanization, while in the Oaks and Prairies it involves a dramatic decline in grasslands resulting from heavy woody encroachment and crop production (Partners in Flight 2001*a*).

The black-capped vireo, which has been designated as endangered (U.S. Fish and Wildlife Service 1987), breeds in central Texas, 2 counties in Oklahoma, and northern Coahuila Mexico (Grzybowski 1995). Several factors are responsible for its decline: (1) the effect of fire suppression on suitable habitat; (2) the effect of overgrazing by goats and sheep on habitat (Graber 1961, Grzybowski 1995); and (3) high rates of brown-headed cowbird brood parasitism (U. S. Fish and Wildlife Service 1991). Brown-headed cowbird brood parasitism can significantly reduce the reproductive success of the black-capped vireo (Hayden et al. 2000).

Another federally listed endangered species is the golden-cheeked warbler (U.S. Fish and Wildlife Service 1990), which only breeds in 25 counties in central Texas (Ladd and Gass 1999). The primary reason for the decline of the golden-cheeked warbler is loss of breeding habitat resulting from habitat destruction (urbanization) and habitat modification (agricultural practices) (U. S. Fish and Wildlife Service 1992). The loss of habitat creates a fragmented breeding habitat which leads to an increase in brown-headed cowbird brood parasitism of golden-cheeked warbler nests.

The brown-headed cowbird parasitizes nests of over 240 species (Friedmann and Kiff 1985) and most of these are Neotropical migrants (Robinson et al. 1993). Species which have a small restricted breeding range can be particularly vulnerable to brood parasitism (Robinson et al. 1993). Nest parasitism rates for the golden-cheeked warbler vary between 68% in Kendall County, Texas (Pulich 1976), and 14% in Travis County Texas (Gass 1996). Species with small populations and known to be highly susceptible to cowbird brood parasitism are likely to benefit from intensive cowbird control programs (Robinson et al. 1993). For the black-capped vireo, parasitism rates at Fort Hood, Texas, were 90.9% before the implementation of a cowbird control program, and dropped to 12.6% after implementation (Hayden et al. 2000).

The black-capped vireo recovery plan calls for the implementation of several management strategies to identify potential habitat, and maintain and create habitat through vegetation manipulation. Furthermore, the plan recommends cowbird control measures in areas where parasitism rates are high (U. S. Fish and Wildlife Service 1991). The recovery plan for the golden-cheeked warbler includes tasks of identifying and protecting existing breeding habitat on private and public lands, and where appropriate, managing for golden-cheeked warbler habitat (U. S. Fish and Wildlife Service 1992).

Habitat Models

Habitat models can more accurately predict occurrence for species which utilize restricted habitat types than for more habitat generalist species (Hepinstall et al. 2002).

For example, Saveraid et al. (2001:79) studied habitat generalist and habitat restrictive species, and concluded that "species that breed in specific habitat types were highly correlated with variables characterizing that habitat." Both the black-capped vireo and golden-cheeked warbler in particular, appear to be "good candidates" for habitat modeling based on their known habitat types.

The black-capped vireo prefers habitat in early successional stages that consist of scrub-oak growth of heterogeneous height and distribution that reaches close to the ground (Graber 1961, Grzybowski et al. 1994). Graber (1961:334) said the black-capped vireo is "restricted in its distribution by rigid requirements of vegetative and climatic factors. It does not adapt to modified conditions and therefore becomes limited in its distribution."

Golden-cheeked warbler breeding habitat is characterized by mature juniper-oak woodlands (Pulich 1976, Ladd 1985, U. S. Fish and Wildlife Service 1992). The preferred habitats are woodlands with a moderate to high density of trees and dense canopy cover at the upper levels. Juniper is most often the dominant tree species. Any juniper material, but especially shredding bark is used to construct the nest (Pulich 1976). Common deciduous oak species include Texas oak (*Quercus buckleyi*), scrub live oak (*Q. fusiformis*), limestone Durand oak (*Q. sinuata*), and Lacey oak (*Q. glaucoides*). Other common deciduous nonoak species include cedar elm, walnut (*Juglans* spp.), hackberry (*Celtis* spp.), and Texas ash (*Fraxinus texensis*). The juniper-oak woodlands preferred by the golden-cheeked warbler typically occur in areas with rugged terrain such as in steep slopes, canyons, and uplands (U.S. Fish and Wildlife Service 1992, Ladd and Gass 1999). Thus, both species have restricted habitat requirements, which may facilitate the development of habitat models.

Species Co-occurrence

Understanding patterns of association or the lack thereof among pairs or group of species has important management implications. For example, co-occurring species may be associated negatively or positively if they are influenced by similar environmental factors, and thus their spatial distribution patterns may not be independent (Pielou 1977:203). This has important implications when considering ecosystem level approaches to species conservation. An understanding of species' patterns of association fits into the priority setting process for multiple species management, and for identifying consequences to other species if high priority species are managed for (Thompson et al. 2000).

Objectives

The Leon River Restoration Project (LRRP) was implemented to restore native rangelands via a brush control program with the objectives of improving wildlife habitat and watershed hydrology by the removal of juniper. This warranted the establishment of a baseline inventory from which results of future treatments may be compared, as monitoring species response to management actions are an important component of adaptive management (Murphy and Noon 1991). Of special interest are 7 breeding bird species found within the Leon River Watershed: black-capped vireo, golden-cheeked warbler, northern bobwhite, white-eyed vireo, Bell's vireo, painted bunting, and brown-headed cowbird. Five of the species were included because of their priority status, but I also included the non-priority species white-eyed vireo and the brood parasite brown-headed cowbird. The white-eyed vireo was included because of concerns that its breeding density may be impacted by the brown-headed cowbird which also negatively impacts the black-capped vireo and golden-cheeked warbler (Hopp et al. 1995).

The purpose of this study was to determine presence and co-occurrence of selected bird species across a range of available habitat types, and to determine those site factors correlated with observed occupancy rates. Ultimately, I wanted to develop models for predicting site occupancy for each selected species based on habitat characteristics correlated with the presence of each species.

STUDY AREA

The area included the Leon River Watershed as it traversed Coryell and Hamilton counties in central Texas (Fig. 1). The area has an average minimum temperature of 0.89 ˚C in January, and an average maximum temperature of 35.88 ˚C in July. Annual rainfall averages 78.90 cm (McCaleb 1985), and elevation is between 183–488 m above sea level (Texas State Historical Association 2003).

The area contains part of 3 Ecoregions: Edwards Plateau, Blackland Prairie, and Oak Woods and Prairies (Texas Parks and Wildlife 2001). Primary land use is in cattle ranching and crop production (McCaleb 1985, National Agricultural Statistics Service 2002). Range vegetation is dominated by oak-ashe juniper woodlands: oak-mesquite-juniper parks/woods, live oak-mesquite-ashe juniper parks, and live oak-ashe juniper woods (McMahan et al. 1984). Common trees include ashe juniper, live oak, and deciduous oaks–including Texas oak, limestone Durand oak, and blackjack oak (*Quercus marilandica*). Other deciduous trees or shrubs include cedar elm, hackberry, and flame-leaf sumac (*Rhus copallina*).

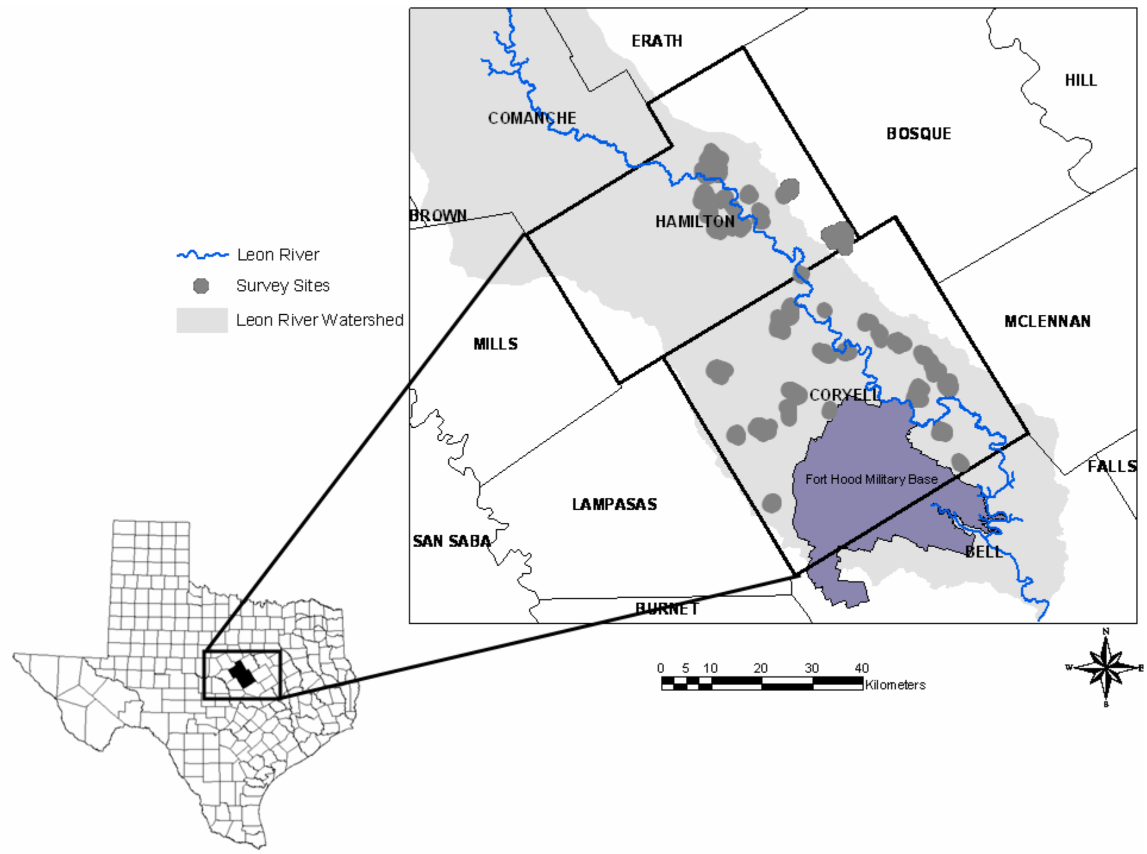

Fig. 1. Study area, the portion of the Leon River Watershed located within Coryell and Hamilton Counties, Texas.

METHODS

Site Selection

Three-hundred and seventy-eight point counts were established which were distributed on private lands across the Leon River Watershed. Because the goal was to survey a range of available habitat types across the landscape (Heglund 2002) the point counts were intentionally distributed across the watershed in approximate proportion to available habitat types. Point count locations were ≥ 400 m a part as a general rule (Ralph et al. 1993). Due to variations in ranch size and shape, it was not always possible to meet the minimum distance requirement at 16% of the sites. Distances at these sites ranged from 204 m to 388 m, but with most being >300 m in spacing.

Avian Surveys

Fixed-radius point counts (Hutto et al. 1986) were used to survey for 7 selected species, black-capped vireo, golden-cheeked warbler, northern bobwhite, white-eyed vireo, Bell's vireo, painted bunting, and brown-headed cowbird. Tape-playbacks were used as a supplementary method for the black-capped vireo and golden-cheeked warbler (Johnson et al. 1981). Survey protocols generally followed methods suggested by Ralph et al. (1993). Surveys were conducted during the breeding season, from 26 March–19 June, 2003 using 3 observers trained to identify selected species by sight, song, and call. Surveys started 15 minutes after local sunrise and concluded by 1100, and were discontinued under adverse weather conditions. Species and number of individuals within a 100 m radius of each point were recorded. The estimated distance (0–25 m, 26–50 m, 51–75 m, or 76–100 m) and general direction (N, E, S, W, NE, SE, NW, or SW) of each bird relative to the center point was also recorded. Each point was surveyed for up to 12 minutes. If no golden-cheeked warbler (or black-capped vireo) had been detected during the initial 6 minute interval, the playback method was used. The method consisted of a 1 minute playback followed by a 2 minute listening period for each of these 2 species. Each point was visited 3 times during the season (Siegel et al. 2001, Dettmers and Bart 1999), and a different observer conducted the point count during each visit in order to minimize observer bias.

The use of local recordings for the black-capped vireo and golden-cheeked warbler tape-playbacks was preferred over commercial ones, due to variations in regional dialects (Johnson et al. 1981). Recordings made from local populations occurring at Fort Hood Texas (Coryell and Bell Counties) were obtained from The Nature Conservancy. Robinson et al. (1993) recommend that when surveying, special attention should made to differentiate between male and female cowbirds, as the level of nest parasitism in an area may be better gauged by evaluating the distribution and abundance of female cowbirds. Thus for the survey, I differentiated between male and female brown-headed cowbirds based on rattle or chatter calls.

Vegetation

Vegetation was measured along four 10 m line transects in the 4 cardinal directions beginning 10 m from the location of the bird-counting point[1]. Percent canopy intercept by woody species in 4 height classes (0–1.5 m, 1.5–3 m, 3–5 m, and >5 m) was recorded for each transect (Bonham 1989).

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[1] Vegetation not measured for 2 of 378 points, which had brush control treatments applied post-survey.

Measures at points also included tree species and number of individuals having a diameter at breast height (dbh) ≥10 cm, and located within a 5 m radius from center of vegetation transect. When multi-trunk trees were encountered, each trunk was counted as a separate "tree". Ground layer variables recorded included relative abundance of ground cover classes (bare ground, rock, litter, forbs, and grass) within a 0.5 x 0.5 m quadrant at 3 intervals (2.5 m, 5 m, and 7.5 m) along each transect.

An additional 10 m transect was sampled that was centered at the approximate location (same direction and distance interval relative to point center) of a black capped vireo or golden-cheeked warbler detection. The same vegetation measurements recorded in the main transects were recorded in these additional transects (hereafter referred to as microsites). Appendix A provides a diagram of the vegetation survey plot.

Data Analysis

A site was classified as occupied by a given species if that species was detected during at least 1 of the 3 visits to the point (Siegel et al. 2001). Additionally, any bird detected as the observer approached or left the point center was included when determining site occupancy, as long as the individual bird was estimated to be within the 100 m radius circle from point center. This more inclusive count (which I refer to as the 12-minute plus count) for determining site occupancy was used in order to maximize the number of observations available for developing the most robust habitat models possible. Although the survey protocol allowed for the possibility of a point count lasting less than 12 minutes, 94.7% of visits had a complete 12-minute survey period.

Furthermore, unless specifically stated, all results presented are based on the more inclusive 12-minute plus count.

A 12-minute count, with no pre- and post-survey detections, was used only for investigating species co-occurrence. The Chi-Square test was used to detect significant associations between co-occurring species pairs, and Cramer's values of association calculated to evaluate the strength of the association (Pielou 1977).

For comparison purposes, I also conducted univariate analyses and model building procedures using species presence/absence derived only from the initial 6-minute count period. This much more conservative dataset excluded any detections made during the tape-playback or pre- and post-survey periods. These results are briefly presented, and will not be discussed in depth.

The vegetation characteristics sampled from each site served as explanatory variables (Mitchell et al. 2001) for understanding species-habitat relationships. The approach taken to organize and analyze all of the vegetation variables was primarily driven by the desire to identify potential biologically important explanatory variables for developing strong habitat models for the black-capped vireo and golden-cheeked warbler. Primarily, I evaluated growth forms of woody plants, but analyzed juniper and live oak by species. Vegetation variables recorded included species composition at various height levels, followed by the subsequent grouping of some height categories for further exploratory analysis. The nonparametric Mann-Whitney test was used to check for significant differences in vegetation variables between species occupied and unoccupied sites. Tree density variables refer to trees with dbh ≥10 cm; although for juniper I also calculated the density of trees with dbh ≥13 cm.

For many bird species vertical heterogeneity of vegetation structure appears to be more important than individual kinds of plant species (MacArthur and MacArthur 1961). Foliage height diversity (FHD) is a measure of the diversity of vegetation in the foliage profile, which has been positively correlated with bird species diversity (MacArthur and MacArthur1961, Wiens 1989, Bibby et al. 2000). The vertical vegetation profile was compared by calculating a FHD index using the Shannon-Wiener formula:

$$H = -\sum p_i \ln p_i$$

Where p_i is the proportion of the total foliage which lies in the *i*th horizontal layer (MacArthur and MacArthur 1961, Bibby et al. 2000:269).

Because site occupancy for each species was affirmed by estimating a bird's presence at the scale of the 100 m radius plot, I wanted to further investigate vegetation characteristics at the finer microsite scale for the 2 species of special concern: the black-capped vireo and golden-cheeked warbler. The Wilcoxon Signed Rank test was used to make paired comparisons between occupied sites and microsites of the black-capped vireo and golden-cheeked warbler. When multiple microsites occurred at an occupied site, the occupied site was paired with more than one microsite to allow for paired comparisons.

Stepwise logistic regression (LR) was used to develop models for predicting the occurrence of each species in the Leon River Watershed. The model building procedures generally followed those recommended by Hosmer and Lemeshow (2000).

The model building process began by fitting a univariate LR model for each variable and examining the Wald Chi-Square. Only those variables with p-values ≤ 0.25 were retained for further analysis. The remaining variables were checked for multicollinearity by calculating a Spearman's rank correlation coefficient (r_s) between all pairs of variables. For each correlated pair ($|r_s| > 0.500$) the decision on which variable to exclude was based on the results of the univariate LR (Robertsen et al. 2002, Klute et al. 2002). Parsimonious models were developed using the backward stepwise selection method as suggested by Menard (2001). The removal of variables was based on the Likelihood ratio statistic (Field 2000), with the p-values set at 0.10 for removal and 0.05 for entry. Following the stepwise procedure, the significance of each variable included in the model was evaluated using the Wald statistic, and any variable with a p-value > 0.05 was manually removed. McFadden's rho squared and Hosmer-Lemeshow tests were used to evaluate the fit of each model. Additionally ROC (receiver operating characteristic) plots were used to measure each model's ability to discriminate (Hosmer and Lemeshow 2000). All statistical tests were computed with SPSS 11.5.1 (SPSS Inc. 1989) or Systat 10 (SPSS Inc. 2000).

Ecological Sites

An ecological site is defined by the Natural Resources Conservation Service (NRCS) as a distinctive kind of land with specific physical characteristics that produces a distinguished natural plant community (McCaleb 1985). Digitized maps of ecological sites for the study area were obtained from the NRCS (National Cartography and Geospatial Center 2002), and crossed checked with maps from the Soil Survey of

Coryell County, Texas (McCaleb 1985). The GPS coordinates of all site locations were plotted on the digital map (using ArcGIS) in order to classify each surveyed site as belonging to 1 of 16 mutually exclusive ecological site types. Due to the low occurrence of 9 of the ecological sites, I focused on the 7 most common ones and used a Chi-Square test to classify each species as preferring or avoiding any of the 7 selected ecological sites.

There are errors of accuracy associated with these kinds of maps because of the process by which they are generated. For example there may be gradual transitions between map units (i.e., ecological sites) which are not depicted (National Cartography and Geospatial Center 2002). Additionally the mapping scale may exclude features found in a heterogeneous landscape that are too small to delineate. Thus the best approach would have been to field verify all classifications; however I believe the map was adequate for exploring any broad general patterns.

RESULTS

Bird Abundance

I recorded 2,295 individuals of the 7 selected species within the 100 m sampling radius of the 378 sites (Table 1). At most sites (74.1%) only 2 or 3 species were detected. The most abundant species were the brown-headed cowbird (n = 1221), and painted bunting (n = 450). The least common species were the black-capped vireo (n = 26), and golden-cheeked warbler (n = 82). The most widespread species was the brown-headed cowbird which occupied 86.8% of sites surveyed, and the least widespread species was the black-capped vireo which occupied only 5.6% of sites surveyed. Species rankings by relative abundance or site occupancy were similar when data were analyzed by 6 or 12 minute counts (Appendix B).

Species Co-occurrence

Analysis of co-occurrence between all possible species pairs revealed significant associations between pair-wise comparisons of the golden-cheeked warbler with each of 5 other species (Table 2). However, the strength of the detected associations was relatively low. The golden-cheeked warbler and northern bobwhite showed the greatest negative association. The northern bobwhite was 70% less likely to occur at sites occupied by the golden-cheeked warbler, while the white-eyed vireo showed the greatest positive association with the golden-cheeked warbler. The white-eyed vireo was 64% more likely to occur at sites occupied by the golden-cheeked warbler than at other sites. The golden-cheeked warbler showed a very weak positive association with the black-capped vireo. The black-capped vireo was twice as likely to occur at sites occupied by the golden-cheeked warbler than on other sites.

Table 1. Number of individuals detected (including pre- and post-survey period detections), number of sites occupied by species, and percent occupancy at 378 survey sites following 3 survey visits, in the Leon River Watershed, Texas.

Species Common Name	Scientific Name	Code[a]	# indiv.	# Sites Occupied	% Occupied
Northern bobwhite	*Colinus virginianus*	NOBO	276	110	29.1
White-eyed vireo	*Vireo griseus*	WEVI	145	102	27.0
Bell's vireo	*Vireo bellii*	BEVI	95	79	20.9
Black-capped vireo	*Vireo atricapillus*	BCVI	26	21	5.6
Golden-cheeked warbler	*Dendroica chrysoparia*	GCWA	82	52	13.8
Painted bunting	*Passerina ciris*	PABU	450	251	66.4
Brown-headed cowbird	*Molothrus ater*	BHCO	1221	328	86.8

[a] Species codes for birds as found in the North American Bird Banding Manual (Gustafson et al. 1997).

Distance to Fort Hood

At first glance it appeared that the black-capped vireo and golden-cheeked warbler tended to occur closer to the Fort Hood Military base (Fort Hood), however based on the general vegetative composition and structure across the sites surveyed, I would expect to find fewer black-capped vireos or golden-cheeked warblers further from Fort Hood. Thus, no discernable distribution patterns were observed in black-capped vireo (Fig. 2) or golden-cheeked warbler (Fig. 3) detections in relation to their distance to Fort Hood, which has the largest known populations of both species under a single management authority (US Fish and Wildlife Service 1991, 1992).

Table 2. Species co-occurrence expressed as the percentage of sites occupied by species B out of all sites occupied by species A, and Cramer's values (V) of association between (significant only) species pairs, in the Leon River Watershed, Texas.

	%, (V)						
	Species B						
Species A	NOBO 26.7[a]	WEVI 25.7	BEVI 20.4	BCVI 5.0	GCWA 13.2	PABU 65.3	BHCO 85.4
Northern bobwhite (NOBO)	—	19.8	19.8	3.0	4.0***[b] (-0.165)	67.3	86.1
White-eyed vireo (WEVI)	20.6	—	20.6	7.2	21.6*** (0.146)	66.0	82.5
Bell's vireo (BEVI)	26.0	26.0	—	3.9	6.5* (-0.101)	59.7	83.1
Black-capped vireo (BCVI)	15.8	36.8	15.8	—	26.3* (0.089)	52.6	94.7
Golden-cheeked warbler (GCWA)	8.0*** (-0.165)	42.0*** (0.146)	10.0* (-0.101)	10.0* (0.089)	—	52.0** (-0.109)	80.0
Painted bunting (PABU)	27.5	25.9	18.6	4.0	10.5** (-0.109)	—	87.9* (0.094)
Brown-headed cowbird (BHCO)	26.9	24.8	19.8	5.6	12.4	67.2* (0.094)	—

[a] Percent occupancy, the expected value, from 378 survey sites (12 minute count only).
[b] Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$ for χ^2 test of association.

Vegetation

I found 44 species of trees and shrubs during this study (Table 3). Common tree species encountered were juniper, live oak, cedar elm, Texas oak, and limestone Durand oak. Common shrubs encountered were narrow-leaf forestiera (*Forestiera angustifolia*), woollybucket bumelia (*Bumelia lanuginosa*), honey mesquite (*Prosopis glandulosa*), and Lindheimer prickly pear (*Opuntia lindheimeri*). The frequencies of (foliar) cover by growth forms or species were positively skewed; they did not appear to exhibit normal distributions (Fig. 4). Zero values (i.e., no cover) for most plant groups were relatively common, ranging from 31% of sites with no shrub cover to 59% of sites with no live oak cover. Juniper cover was the most frequently encountered cover type with only 9% of sites having zero values.

As expected when collecting multiple vegetation variables, many intercorrelations among the variables were found. A Spearman rank correlation matrix revealed some obvious intercorrelations within each woody plant group or species among cover, vertical foliage profile, and density of trees. For example, juniper cover was strongly positively correlated with the juniper vertical profile (r_s = 0.924–0.968; n = 376; $p < 0.001$), and juniper tree density ($r_s = 0.861$; $p < 0.001$). Other associations were as follows: juniper cover was positively correlated with ground cover of litter (r_s = 0.627; $p < .001$) and negatively correlated with ground cover of forbs ($r_s = -0.606$; $p <$ 0.001) and grasses ($r_s = -0.529$; $p < 0.001$). Similar trends were observed with several of the other juniper variables (e.g., foliage profile and tree density). Among the ground layer cover classes, litter showed a negative correlation with forbs ($r_s = -0.659$; $p <$

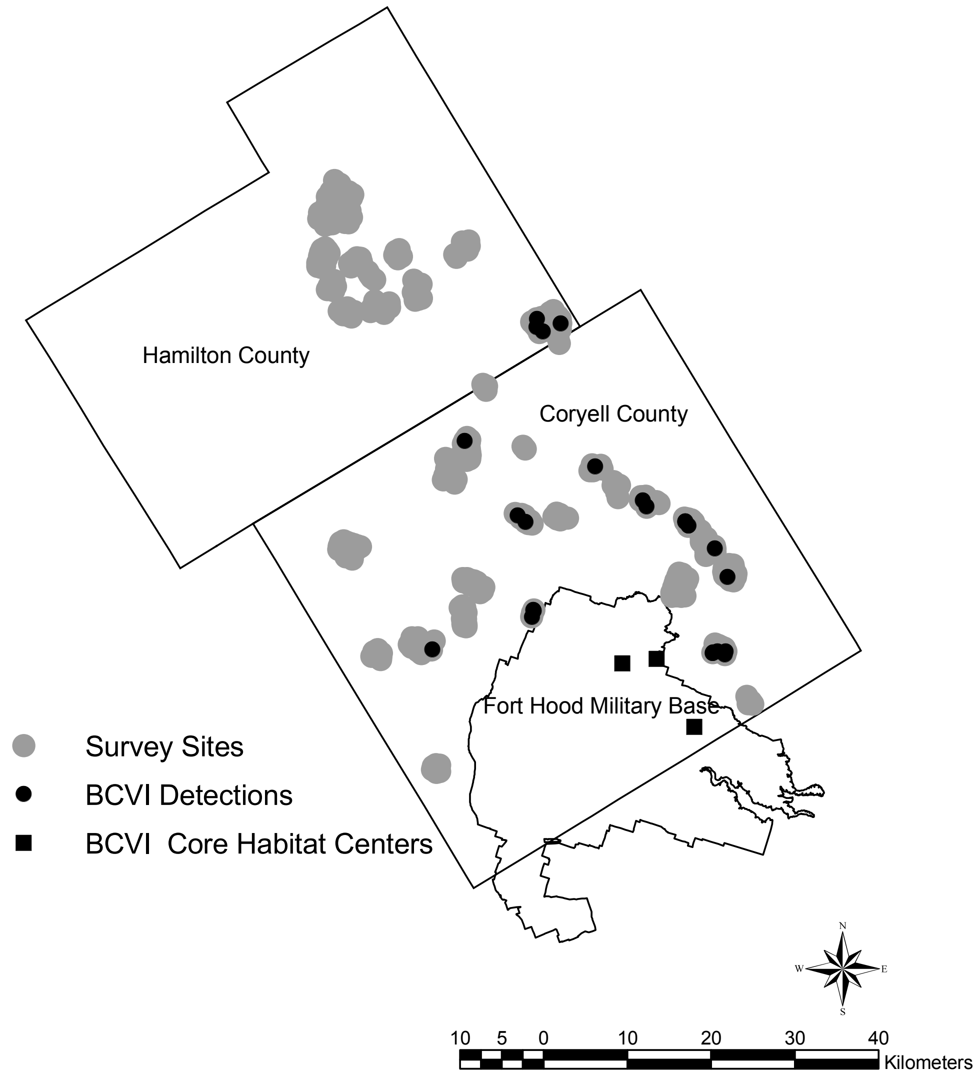

Fig. 2. Distribution of survey sites, with black-capped vireo (BCVI) detections. Also shown is the Fort Hood military base, which has the largest known populations of black-capped vireos of any single management authority (U.S. Fish and Wildlife Service 1991). Black-capped vireo core habitat centers within the base, derived from published maps (Deboer and Koloszar 2001), are displayed for comparison to detections made outside the base.

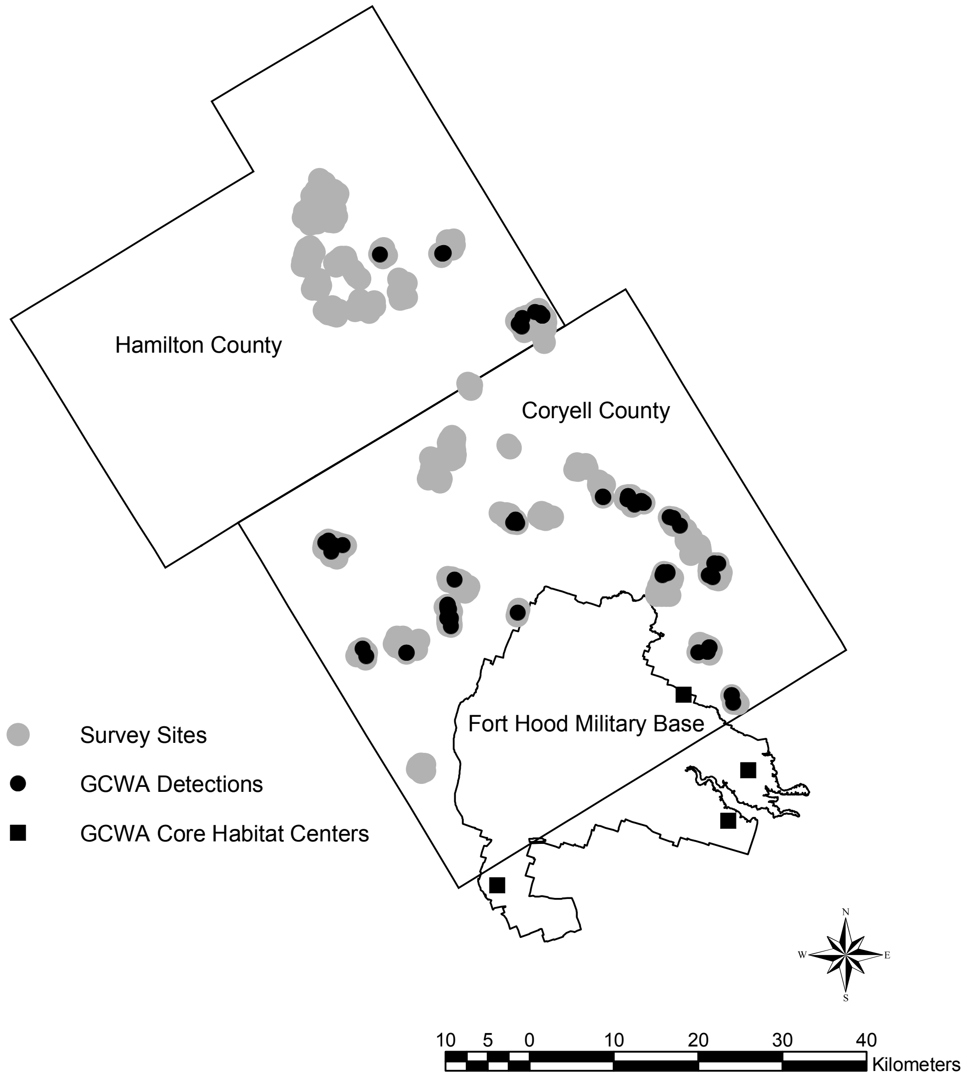

Fig. 3. Distribution of survey sites, with golden-cheeked warbler (GCWA) detections. Also shown is the Fort Hood military base, which has the largest known populations of golden-cheeked warblers of any single management authority (U.S. Fish and Wildlife Service 1992). Golden-cheeked warbler core habitat centers within the base, derived from published maps (Anders 2001), are displayed for comparison to detections made outside the base.

0.001) and grasses ($r_s = -0.699$; $p < 0.001$), while forbs and grasses expressed a positive correlation ($r_s = 0.540$; $p < 0.001$).

Juniper was present at 308 of the 376 sites ranging in cover from 0 to 95%. Where present, juniper cover for each of 4 height categories was as follows, 0–1.5 m: $\bar{x}$ = 25% (max 87%), 1.5–3 m: $\bar{x}$ = 33% (max 93%), 3–5 m: $\bar{x}$ = 29% (max 91%), and >5 m: $\bar{x}$ = 12% (max 58%). Over-all juniper cover averaged 29.5%. Live oak cover ranged from 0 to 73% ($\bar{x}$ = 7.4), and was present at 154 out of 376 sites. Deciduous oaks cover ranged from 0 to 97%, and was present at 173 out of 376 sites. Where present, average deciduous oaks cover at the 0–1.5 m height was 7% (max 64%), 11% (max 62%) at the 1.5–3 m height, 16% (max 94%) at the 3–5 m height, and 14% (max 62%) at the >5 m height. Deciduous oaks cover across all sites averaged 8.6%. Deciduous nonoaks cover ranged from 0 to 84% ($\bar{x}$ = 10.1), and was present at 193 out of 376 sites. Shrubs cover ranged from 0 to 59% ($\bar{x}$ = 8.6), and was present at 258 out of 376 sites. All non-juniper vegetation was grouped as low-growing (<1.5 m) and midlevel (<3 m) hardwood vegetation for further analysis. Low-growing hardwood cover ranged from 0 to 64% ($\bar{x}$ = 9.7), and was present at 304 out of 376 sites.

Ecological Sites

Both black-capped vireos (Fig. 5), and golden-cheeked warblers (Fig. 6) preferred Low Stony Hill sites. Additionally, golden-cheeked warblers preferred Steep Adobe sites, but avoided Adobe/Shallow sites (Appendix F). Northern bobwhites

Table 3. Woody plant species, identified as to how they were grouped for exploratory analysis. Nomenclature follows Vines (1984).

Common Name	Scientific Name	Group
Catclaw acacia	*Acacia greggii*	Shrub
Seepwillow	*Baccharis salicifolia*	Shrub
Woollybucket bumelia	*Bumelia lanuginosa*	Shrub
Pecan	*Carya illinoinensis*	Deciduous nonoaks
Sugar hackberry	*Celtis laevigata*	Deciduous nonoaks
Common button-bush	*Cephalanthus occidentalis*	Shrub
Eastern redbud	*Cercis canadensis*	Shrub
Rough-leaf dogwood	*Cornus drummondii*	Shrub
Hawthorn spp.	*Crataegus spp.*	Shrub
Texas persimmon	*Diospyros texana*	Shrub
Narrow-leaf forestiera	*Forestiera angustifolia*	Shrub
Texas ash	*Fraxinus texensis*	Deciduous nonoaks
Possum-haw Holly	*Ilex decidua*	Shrub
Yaupon holly	*Ilex vomitoria*	Shrub
Texas black walnut	*Juglans microcarpa*	Deciduous nonoaks
Ashe juniper	*Juniperus ashei*	Ashe juniper
Golden-ball lead-tree	*Leucaena retusa*	Shrub
Osage-orange	*Maclura pomifera*	Deciduous nonoaks
China-berry	*Melia azedarach*	Shrub
White mulberry	*Morus alba*	Deciduous nonoaks
Lindheimer prickly pear	*Opuntia lindheimeri*	Shrub
Eastern Cottonwood	*Populus deltoides*	Deciduous nonoaks
Honey mesquite	*Prosopis glandulosa*	Shrub
Mexican plum	*Prunus mexicana*	Shrub
Black cherry	*Prunus serotina*	Shrub
Blackjack oak	*Quercus marilandica*	Deciduous oaks
Chinquapin oak	*Quercus muhlenbergii*	Deciduous oaks
Water oak	*Quercus nigra*	Deciduous oaks
Limestone Durand oak	*Quercus sinuata*	Deciduous oaks
Post oak	*Quercus stellata*	Deciduous oaks
Texas oak	*Quercus texana*	Deciduous oaks
Live oak	*Quercus virginiana*	Live oak
Carolina buckthorn	*Rhamnus caroliniana*	Shrub
Skunk-bush sumac	*Rhus aromatica*	Shrub
Flame-leaf sumac	*Rhus copallina*	Shrub
Saw greenbriar	*Smilax bona*	Shrub
Poison-ivy	*Toxicodendron radicans*	Shrub
American elm	*Ulmus americana*	Deciduous nonoaks
Cedar elm	*Ulmus crassifolia*	Deciduous nonoaks
Unknown		Shrub
Mustang grape	*Vitis mustangensis*	Shrub
Texas yucca	*Yucca rupicola*	Shrub
Lime pricklyash	*Zanthoxylum fagara*	Shrub
Tickletongue	*Zanthoxylum parvum*	Shrub
Lote-bush condalia	*Zizyphus obtusifolia*	Shrub

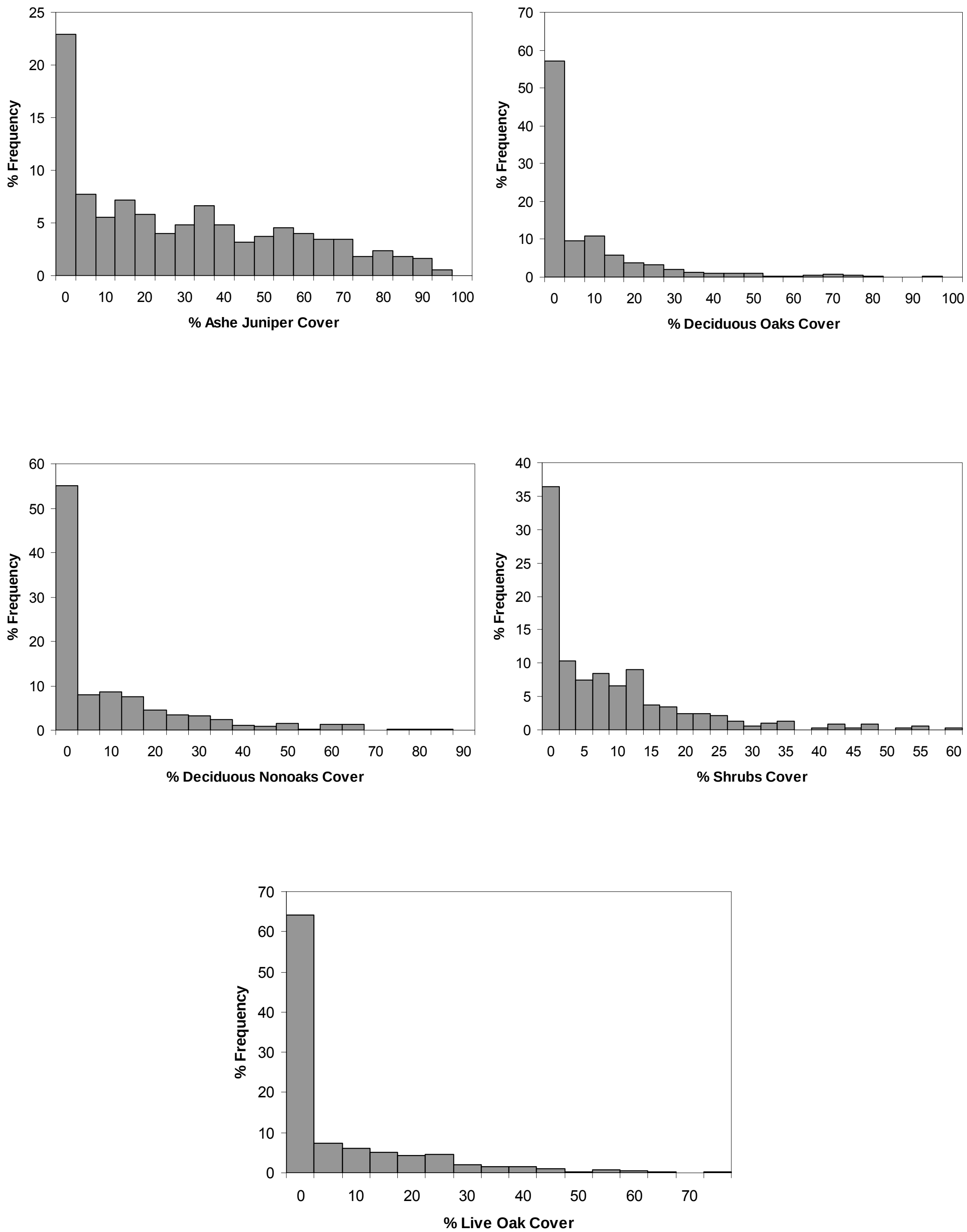

Fig. 4. Histograms representing the frequency (percent of sites) of woody plants cover, occurring across 376 survey sites in the Leon River Watershed, Texas. Note the different scales for the axes.

were least likely to be found on Steep Adobe sites (Fig. 7). Steep Adobe and Low stony hill sites were characterized by greater amounts of juniper (including juniper cover >3 m), and deciduous oaks, and lower live oak cover when individually compared to all other sites (Appendix G, Appendix H). Steep Adobe sites also tended to have less shrub cover than other sites.

Clay Loam and Loamy Bottomland sites were preferred by white-eyed vireos (Fig. 8, Appendix F), and Bell's vireos avoided Stony Clay Loam sites (Fig. 9). Juniper (including juniper cover >3 m) and deciduous trees occurred in lesser amounts across Adobe/Shallow sites, while live oak cover was greater in these sites than in all other sites (Appendix G, Appendix H). For Stony Clay Loam sites, the only difference was lower deciduous oaks cover and greater abundance of live oak trees than at all other sites. The brown-headed cowbird and painted bunting did not show a preference for any of the sites.

Low Stony Hill and Steep Adobe sites tended to have more rock cover and less cover of bare ground cover than in all other sites. Additionally, litter cover was more abundant and grass cover less so in Steep Adobe sites (Appendix I).

To explore birds' associations with ecological sites at a finer scale, I evaluated the relationship between ecological sites and microsites of the black-capped vireo and golden-cheeked warbler. For black-capped vireo microsites, 46% were found in Low Stony Hill sites, 31% in Adobe/Shallow sites, and 19% in Steep Adobe sites. Since Low Stony Hill sites were the more common sites I wanted to evaluate microsites' proximity to these sites. Sixty-nine % of microsites were within 50 m of a Low Stony Hill site.

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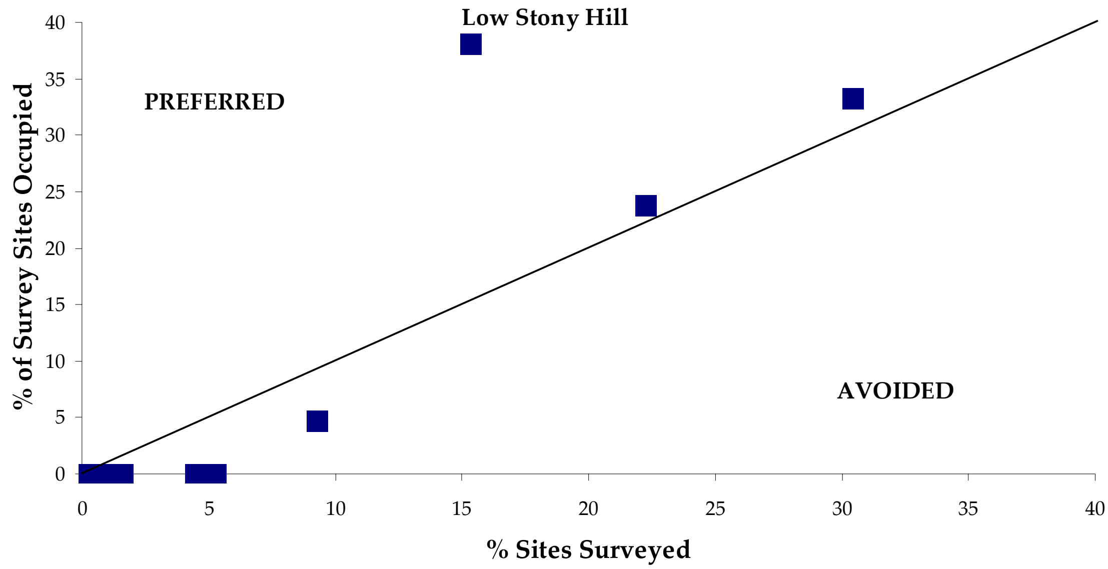

Fig. 5. Percent ecological sites surveyed versus percent occupancy for black-capped vireos in the Leon River Watershed, Texas. Only significant associations are labeled.

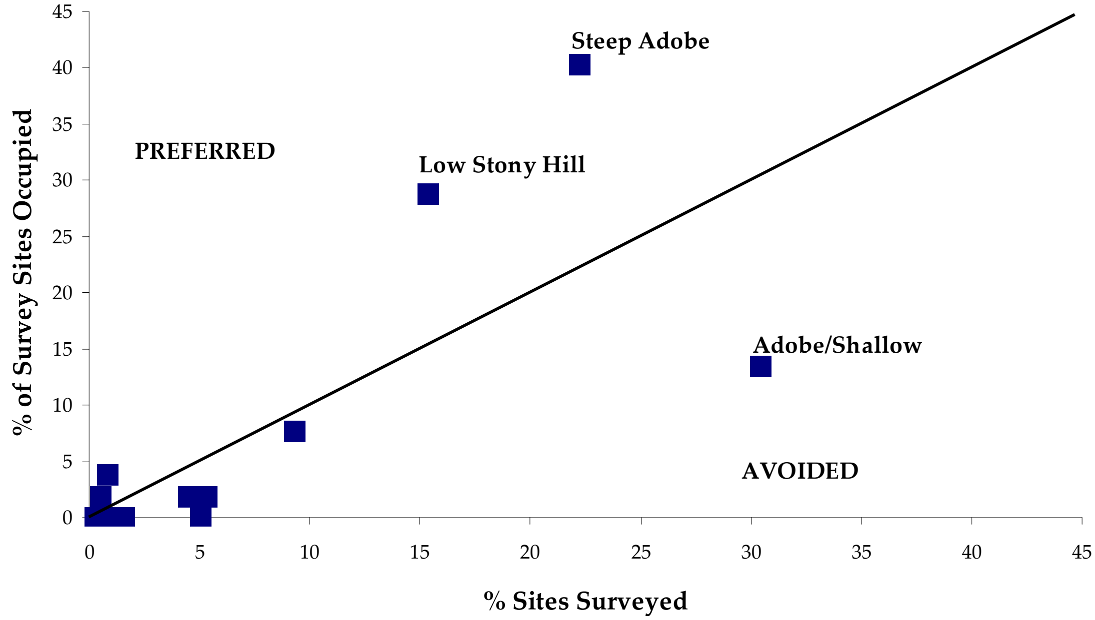

Fig. 6. Percent ecological sites surveyed versus percent occupancy for golden-cheeked warblers in the Leon River Watershed, Texas. Only significant associations are labeled.

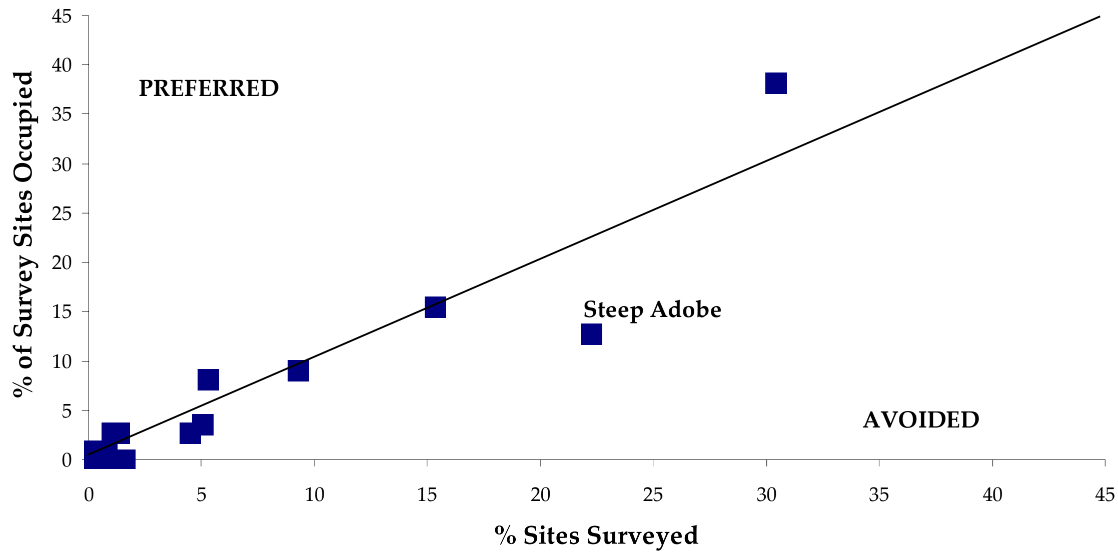

Fig. 7. Percent ecological sites surveyed versus percent occupancy for northern bobwhites in the Leon River Watershed, Texas. Only significant associations are labeled.

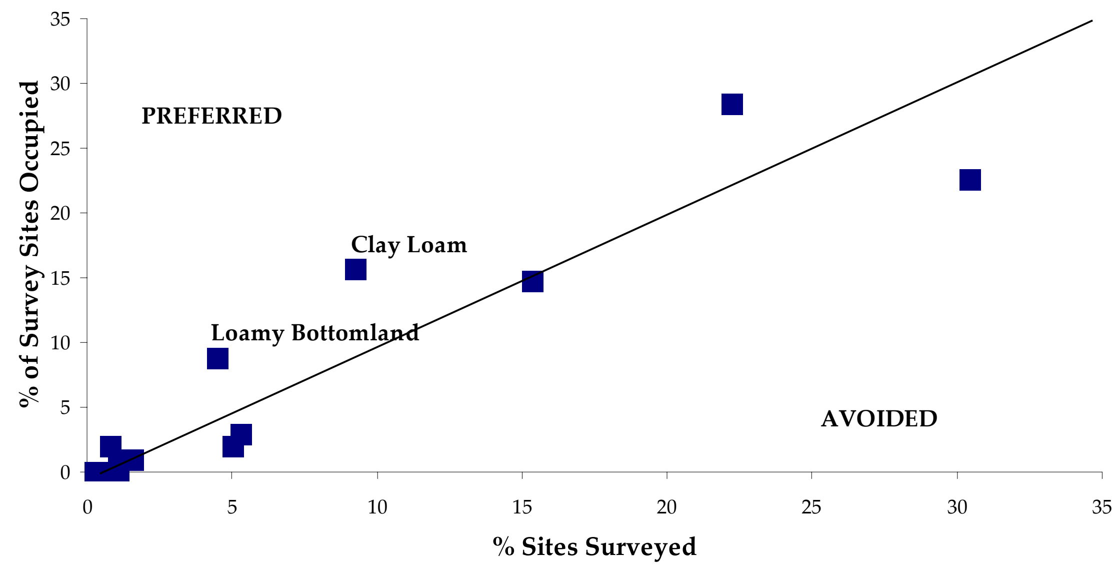

Fig. 8. Percent ecological sites surveyed versus percent occupancy for white-eyed vireos in the Leon River Watershed, Texas. Only significant associations are labeled.

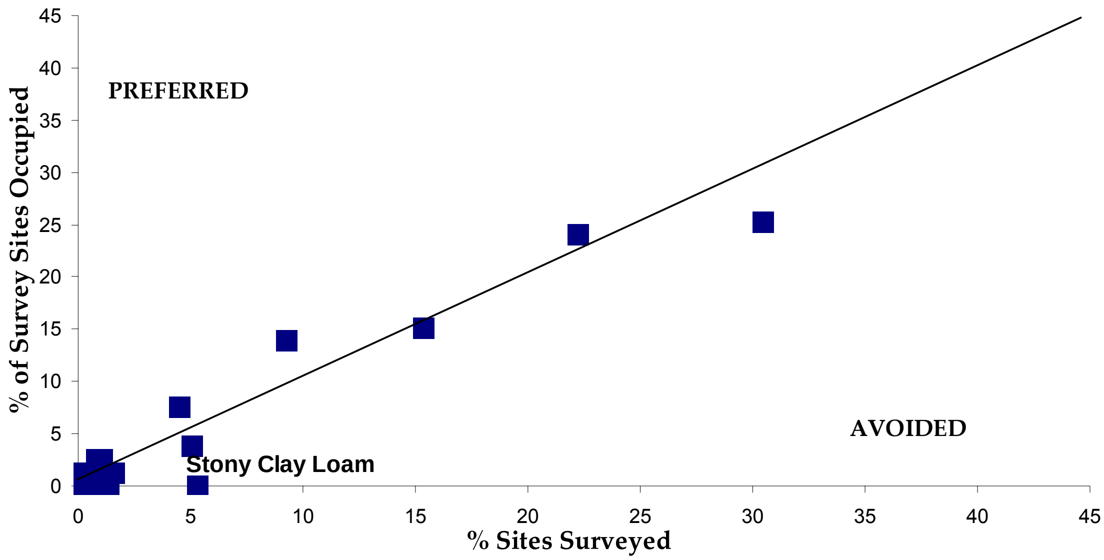

Fig. 9. Percent ecological sites surveyed versus percent occupancy for Bell's vireos in the Leon River Watershed, Texas. Only significant associations are labeled.

For the remaining microsites (31%), their proximity ranged from 225 m to 9,580 m, and all occurring in Adobe/Shallow sites. For golden-cheeked warbler microsites, 43% were found in Steep Adobe and 27% in Low Stony Hill sites. Furthermore, I evaluated all golden-cheeked warbler microsites as to their proximity to a Steep Adobe site. Sixty percent of microsites were within 50 m of a Steep Adobe site, 76% were within 100 m, 83% within 150 m, and 93% within 430 m. In Coryell and Hamilton counties, Low Stony Hill and Steep Adobe sites can occur in 1 of 3 Lower Cretaceous limestones, Fredericksburg, Trinity, or Washita (Schruben et al. 1997). Most (81 %) black-capped vireo microsites occurred on the Fredericksburg group. Similarly, most (68%) golden-cheeked warbler microsites occurred on this same formation.

Occupied Sites

I conducted univariate comparisons between occupied and unoccupied sites of 41 explanatory variables for each of the 7 species. The number of (significant) differences varied by species, with the white-eyed vireo having the most (28) variables, followed in decreasing order by northern bobwhite (26) and golden-cheeked warbler (25). At an intermediate level was the brown-headed cowbird, having 16 variables with differences. The least number of differences were found in the Bell's vireo (6), black-capped vireo (7), and painted bunting (9).

Sites occupied by the black-capped vireo tended to have more low-growing cover by deciduous oaks and greater amounts of deciduous nonoaks in the mid canopy (1.5–5 m) (Table 4, Figs. 10 and 11).

The golden-cheeked warbler occupied sites with greater cover and tree density of juniper and deciduous oaks, and with lesser amounts of live oak and shrubs (Table 4, Fig. 12). Juniper cover at golden-cheeked warbler occupied sites was greater in all vegetation layers, and deciduous oaks cover was greater below the overstory canopy (<5 m) (Fig. 13). Live oak cover was less at the lower half of canopy (≤3 m). All ground cover classes in golden-cheeked warbler occupied sites differed from unoccupied sites; bare ground, forbs, and grasses were lower, while rock and litter were higher (Table 5).

Sites occupied by the northern bobwhite had greater cover of shrubs and low-growing hardwood vegetation (Table 6). Occupied sites also had greater amounts of

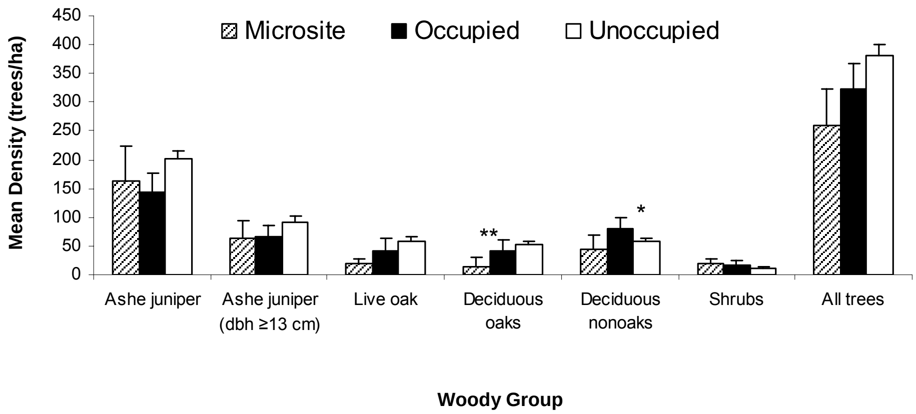

Fig. 10. Mean (+SE) density (trees/ha) by woody plant group for microsites, occupied sites and unoccupied sites of the black-capped vireo, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \le 0.10$, $^{**}P \le 0.05$, or $^{***}P \le 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

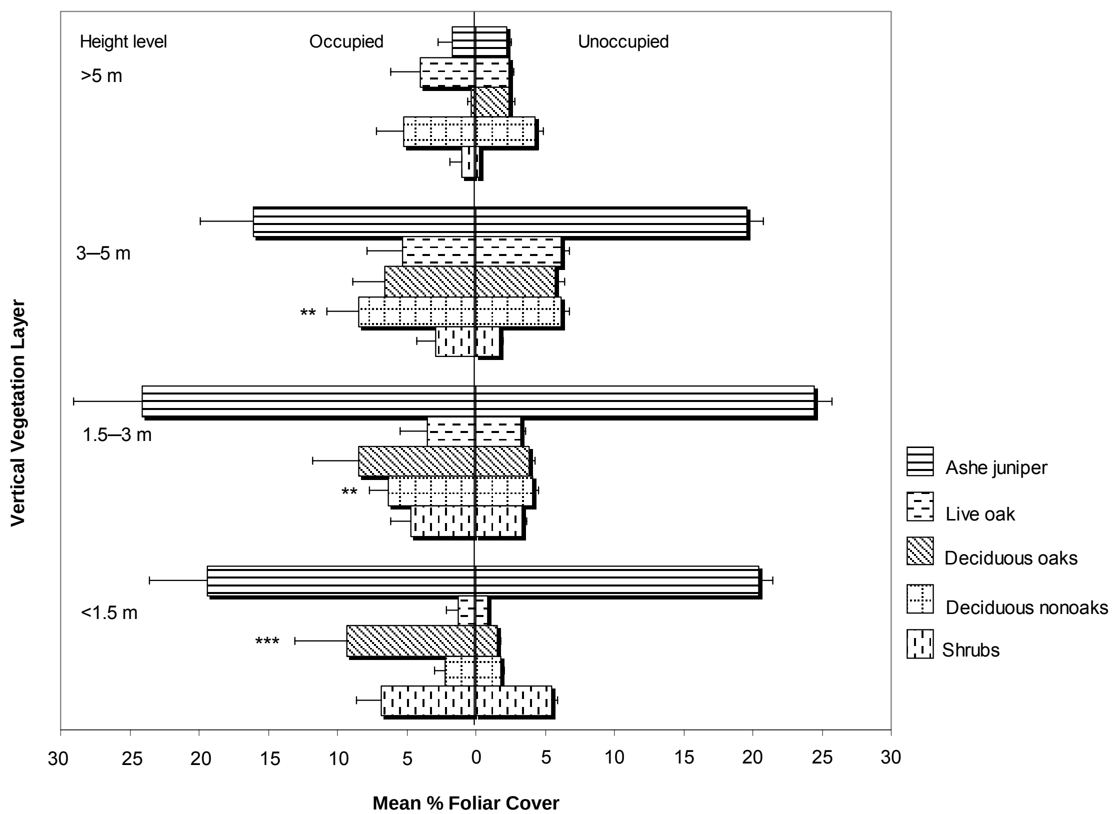

Fig. 11. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the black-capped vireo in the Leon River Watershed, Texas. Significant at $^{*}P \le 0.10$, $^{**}P \le 0.05$, or $^{***}P \le 0.01$.

Table 4. Mean % foliar cover by woody plant group composition for black-capped vireo and golden-cheeked warbler microsites, occupied sites, and unoccupied sites in the Leon River Watershed, Texas.

	Black-capped vireo[a]						Golden-cheeked warbler					
	Microsites (*n* = 26)		Occupied (*n* = 21)		Unoccupied (*n* = 355)		Microsites (*n* = 73)		Occupied (*n* = 52)		Unoccupied (*n* = 324)	
Woody Group	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	16.9	6.0	27.8	5.0	29.6	1.4	49.1	4.0	43.3	3.2	27.3***[b]	1.5
Live oak	5.9	4.0	7.5	3.3	7.4	0.7	4.0	1.7	5.3	1.7	7.7*	0.7
Deciduous oaks	12.8**	4.5	15.1	4.6	8.3	0.8	16.3	3.1	13.5	2.4	7.9***	0.8
Deciduous nonoaks	12.1	4.6	13.5	3.1	9.9**	0.9	11.8	2.8	9.4	2.2	10.3	0.9
Shrubs	13.2	3.3	11.0	2.6	8.5	0.6	5.4	1.3	6.7	1.3	8.9*	0.6
Hardwoods (<1.5 m)	18.6	3.7	18.5	3.9	9.2**	0.6	7.6	1.3	7.9	1.3	10.0	0.6
Hardwoods (<3 m)	24.6	4.8	27.3	3.8	16.9***	0.8	16.0	2.4	15.3	2.1	17.9	0.8
Ashe juniper (>3 m)	9.3*	4.5	16.6	3.8	19.6	1.2	35.3	4.0	29.2	3.0	17.9***	1.2

[a] Comparison of microsites to occupied sites (Wilcoxon Signed Rank test), and comparison of occupied sites and unoccupied sites (Mann-Whitney tests).

[b] Significant at $^{*}P \le 0.10$, $^{**}P \le 0.05$, or $^{***}P \le 0.01$.

Table 5. Mean % ground cover for the black-capped vireo and golden-cheeked warbler microsites, occupied sites, and unoccupied sites in the Leon River Watershed, Texas.

	Black-capped vireo[a]						Golden-cheeked warbler					
	Microsites (n = 26)		Occupied (n = 21)		Unoccupied (n = 355)		Microsites (n = 73)		Occupied (n = 52)		Unoccupied (n = 324)	
Ground cover	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	14.9	4.7	11.9	2.8	10.7	0.5	6.5***[b]	1.6	8.8	1.4	11.1**	0.6
Rock	11.8	3.0	10.1	2.9	9.1	0.6	12.3***	2.2	13.6	1.8	8.4***	0.6
Litter	44.8	6.2	49.0	4.5	45.4	1.2	58.7	3.6	54.9	2.4	44.1***	1.3
Forbs	6.9	2.1	7.6	1.6	8.5	0.4	3.7*	0.8	5.1	0.8	9.0***	0.5
Grass	16.2	3.0	18.6	3.3	25.5	1.0	11.9**	2.0	17.5	2.0	26.4***	1.1

[a] Comparison of microsites versus occupied sites (Wilcoxon Signed Rank test), and comparison of occupied sites versus unoccupied sites (Mann-Whitney test).

[b] Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

of live oak, and lesser amounts of juniper and deciduous oaks (Table 6, Fig. 14). Differences in cover of deciduous oaks occurred above the lowest canopy category (≥1.5 m), while for live oak and juniper cover the differences occurred below the overstory canopy (<5 m) (Fig. 15). Occupied sites tended to have more cover of forbs and grasses, and less litter cover (Appendix C).

Sites the white-eyed vireo occupied generally had more juniper and deciduous nonoaks, with less live oak (Table 6, Fig. 16). These sites also had greater deciduous oaks and shrub cover. When explored by vertical vegetation layers these sites had (1) greater juniper cover in the upper half (≥3 m) of canopy, (2) greater deciduous nonoaks cover across all vegetation layers, and (3) less live oak cover at the mid to upper canopy levels (1.5–5 m) (Fig. 17). Over-all, sites occupied by the white-eyed vireo had greater hardwood vegetation cover in the lower half of canopy (<3 m) (Table 6). In terms of ground cover, occupied sites had higher litter cover, and lower cover of forbs and grasses (Appendix C).

Sites occupied by the Bell's vireo had lesser amounts of live oak (Table 6, Fig. 18), with differences in live oak cover detected in the upper half of canopy (≥3 m) (Fig. 19). None of the measured juniper variables varied between occupied and unoccupied sites.

For the painted bunting, occupied sites had a greater abundance of live oak trees (Fig. 20), with live oak cover generally being greater in the mid to upper canopy levels (1.5─5 m) (Fig. 21). There were no differences in juniper variables between occupied

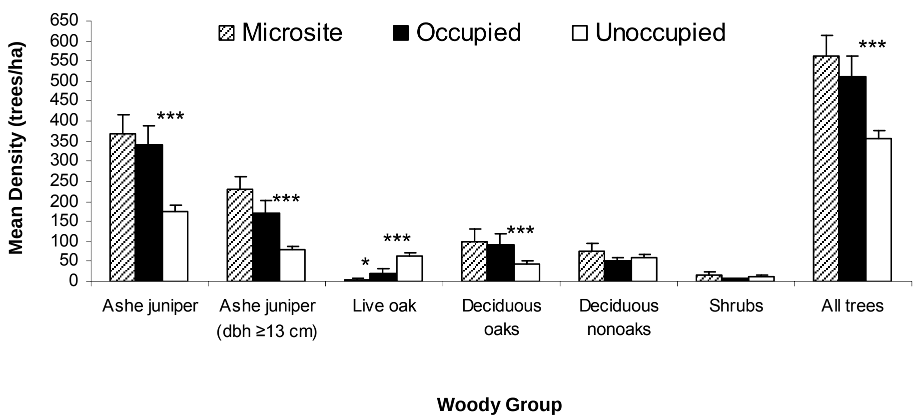

Fig. 12. Mean (+SE) density (trees/ha) by woody plant group for microsites, occupied sites, and unoccupied sites of the golden-cheeked warbler, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

Fig. 13. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the golden-cheeked warbler in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

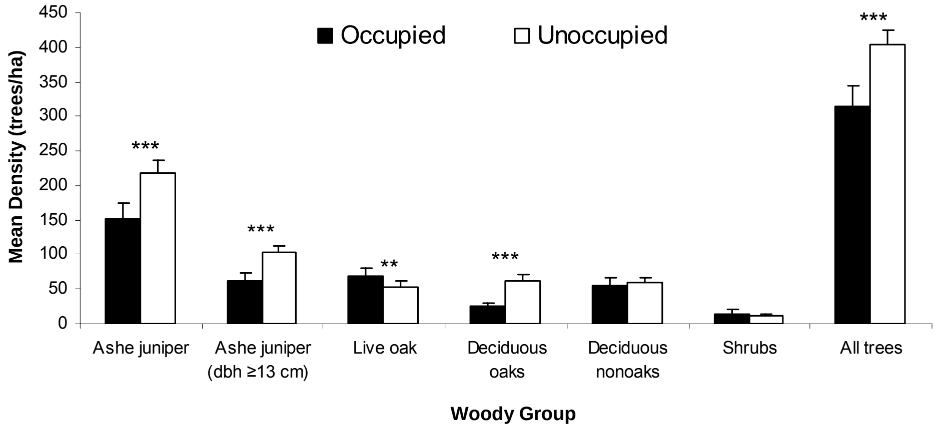

Fig. 14. Mean (+SE) density (trees/ha) by woody plant group for occupied and unoccupied sites of the northern bobwhite, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

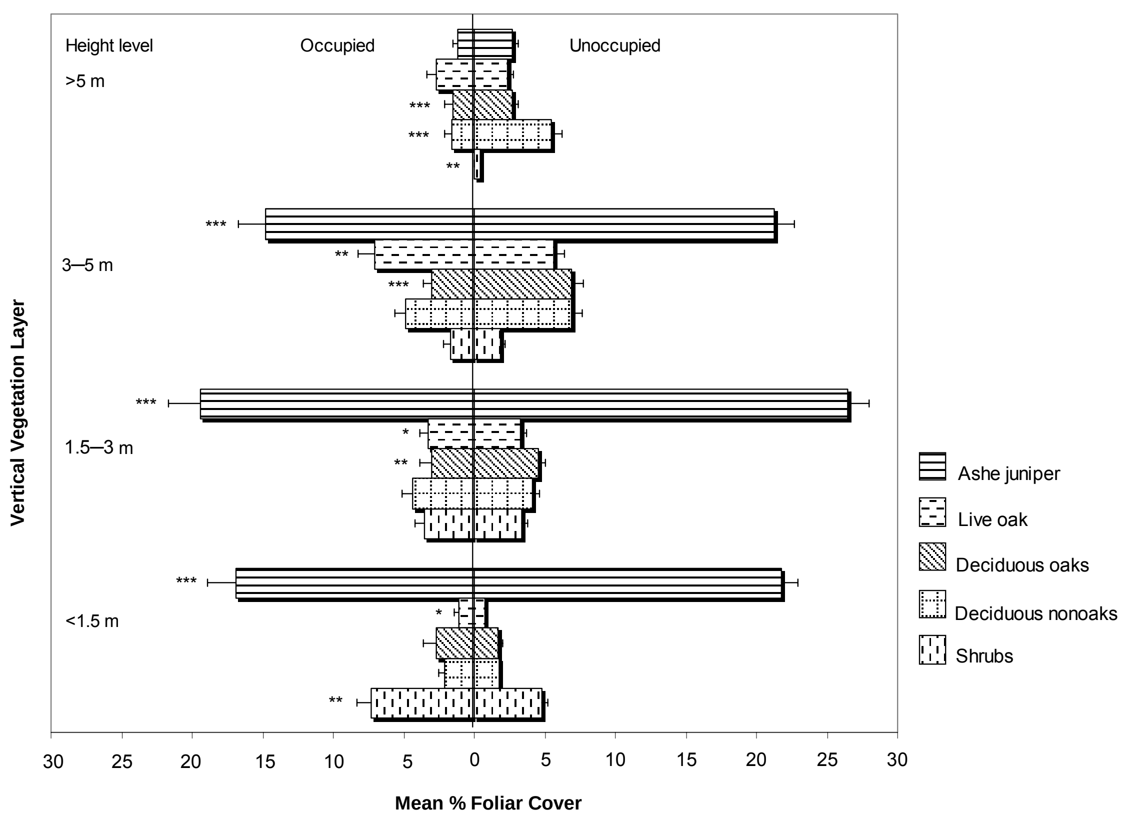

Fig. 15. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the northern bobwhite in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

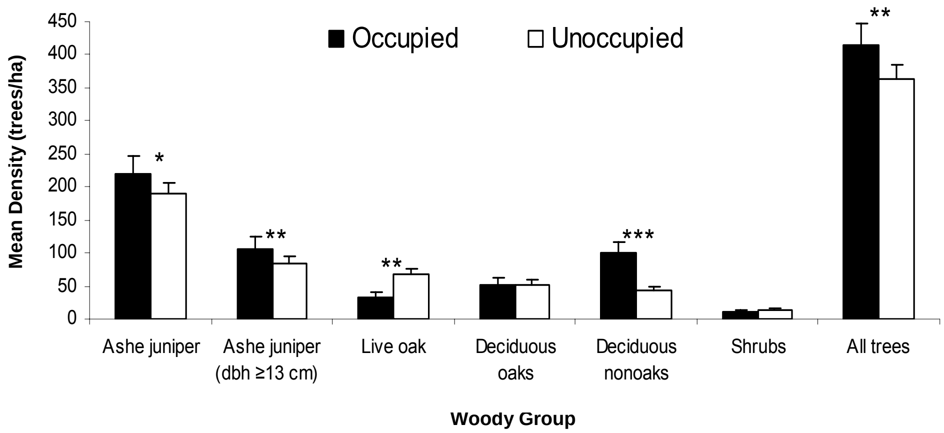

Fig. 16. Mean (+SE) density (trees/ha) by woody plant group for occupied and unoccupied sites of the white-eyed vireo, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

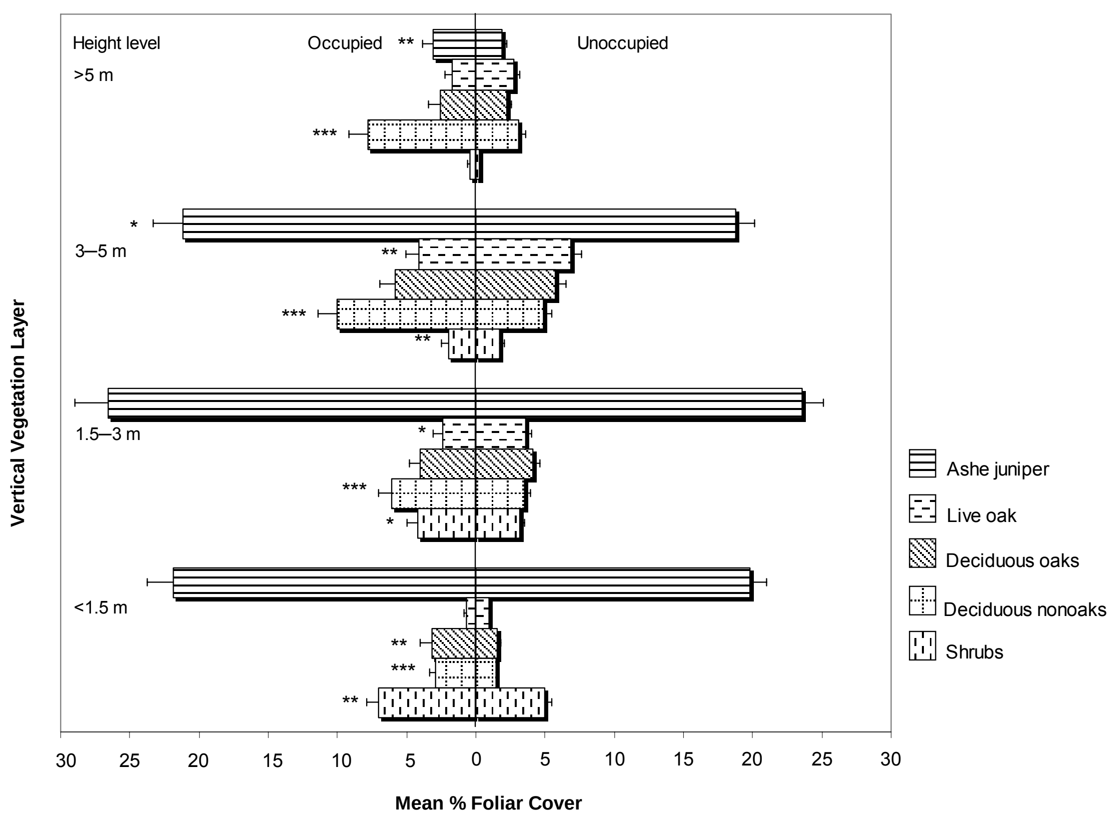

Fig. 17. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the white-eyed vireo in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

Table 6. Mean % foliar cover by woody plant group composition for bird species occupancy, from 376 sites in the Leon River Watershed, Texas

	Northern bobwhite				White-eyed vireo				Bell's vireo			
	Occupied (n = 110)		Unoccupied (n = 266)		Occupied (n = 102)		Unoccupied (n = 274)		Occupied (n = 79)		Unoccupied (n = 297)	
Woody group	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	22.3***[a]	2.4	32.5	1.7	33.4**	2.5	28.0	1.6	28.6	2.8	29.7	1.6
Live oak	8.6**	1.3	6.9	0.8	4.9**	1.1	8.3	0.8	4.3**	1.0	8.2	0.8
Deciduous oaks	6.3***	1.3	9.6	1.0	10.3**	1.6	8.0	0.9	10.2	2.2	8.2	0.8
Deciduous nonoaks	7.3	1.1	11.3	1.1	16.6***	2.1	7.7	0.8	12.8	2.2	9.4	0.9
Shrubs	10.2*	1.2	7.9	0.6	11.1**	1.2	7.7	0.6	8.8	1.1	8.5	0.7
Hardwoods (<1.5 m)	12.7**	1.3	8.5	0.6	13.1***	1.3	8.5	0.6	10.3	1.2	9.6	0.7
Hardwoods (<3 m)	18.1	1.5	17.3	0.9	20.7**	1.5	16.3	0.8	18.6	1.6	17.2	0.8
Ashe juniper (>3 m)	14.8***	1.9	21.4	1.4	21.3*	2.1	18.8	1.4	19.1	2.3	19.6	1.3

Table 6. Continued

Woody Group	Painted bunting				Brown-headed cowbird				Total	
	Occupied (n = 250)		Unoccupied (n = 126)		Occupied (n = 326)		Unoccupied (n = 50)		(n = 376)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	28.8	1.7	30.8	2.3	28.1**	1.4	38.8	4.2	29.5	1.4
Live oak	8.0	0.8	6.1	1.1	7.7	0.8	5.1	1.4	7.4	0.7
Deciduous oaks	7.8	0.9	10.3	1.6	8.4	0.9	10.0	2.2	8.6	0.8
Deciduous nonoaks	9.7	1.0	11.0	1.6	9.2*	0.8	16.3	3.2	10.1	0.8
Shrubs	8.6	0.7	8.7	1.0	8.3	0.6	10.4	1.9	8.6	0.6
Hardwoods (<1.5 m)	10.1	0.7	9.0	0.9	9.6	0.6	10.5	1.8	9.7	0.6
Hardwoods (<3 m)	17.6	0.9	17.4	1.3	17.5	0.8	17.8	2.1	17.5	0.8
Ashe juniper (>3 m)	19.1	1.4	20.3	2.0	18.0***	1.2	28.9	3.8	19.5	1.2

[a] Significant at *$P \leq 0.10$, **$P \leq 0.05$, or ***$P \leq 0.01$ when comparing occupied versus unoccupied sites (Mann-Whitney tests).

unoccupied sites. Forbs cover was higher, and rock cover lower in occupied sites (Appendix C).

The Brown-headed cowbird was found in areas with lesser amounts of juniper and deciduous nonoaks (Table 6, Fig. 22). These occupied sites had less juniper cover below the overstory canopy, and less cover of deciduous vegetation in the upper canopy levels (Fig. 23). The middle canopy (1.5-3 m) had greater cover of live oak than unoccupied sites. Occupied sites generally had lesser amounts of litter cover, and greater amounts of bare ground than unoccupied sites (Appendix C).

A separate analysis using site occupancy for just female brown-headed cowbirds indicated that female occupied sites did not have a lower cover of deciduous oaks in the overstory canopy, nor a higher midstory cover of live oak. Ground layer cover of forbs was higher in these female cowbird sites than unoccupied sites.

For comparison purposes, I also used the more conservative 6-minute point counts to determine presence/absence for use in univariate analyses for all 7 species. The results obtained using the 6-minute point counts showed similar patterns to those obtained using the 12-minute plus counts (with pre- and post survey detections included). Those results are presented in Appendix D.

Microsites

Although black-capped vireo occupied and unoccupied sites did not differ in their amounts of deciduous oaks, lesser amounts of deciduous oaks occurred at

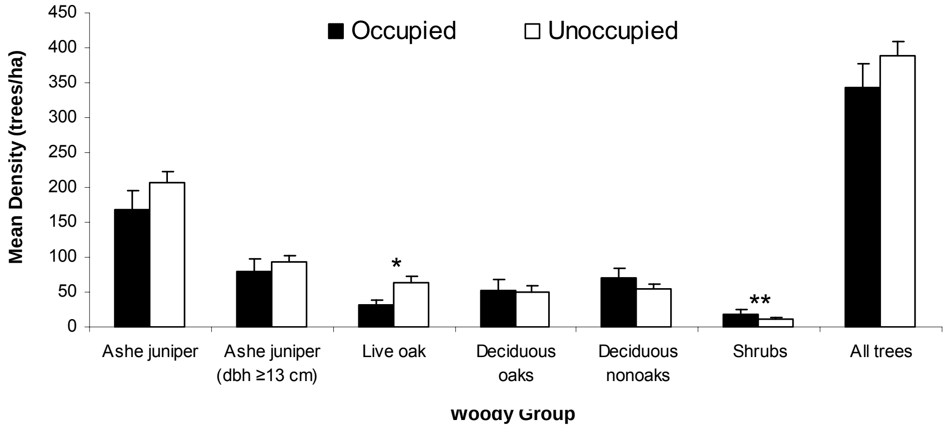

Fig. 18. Mean (+SE) density (trees/ha) by woody plant group for occupied and unoccupied sites of the Bell's vireo, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

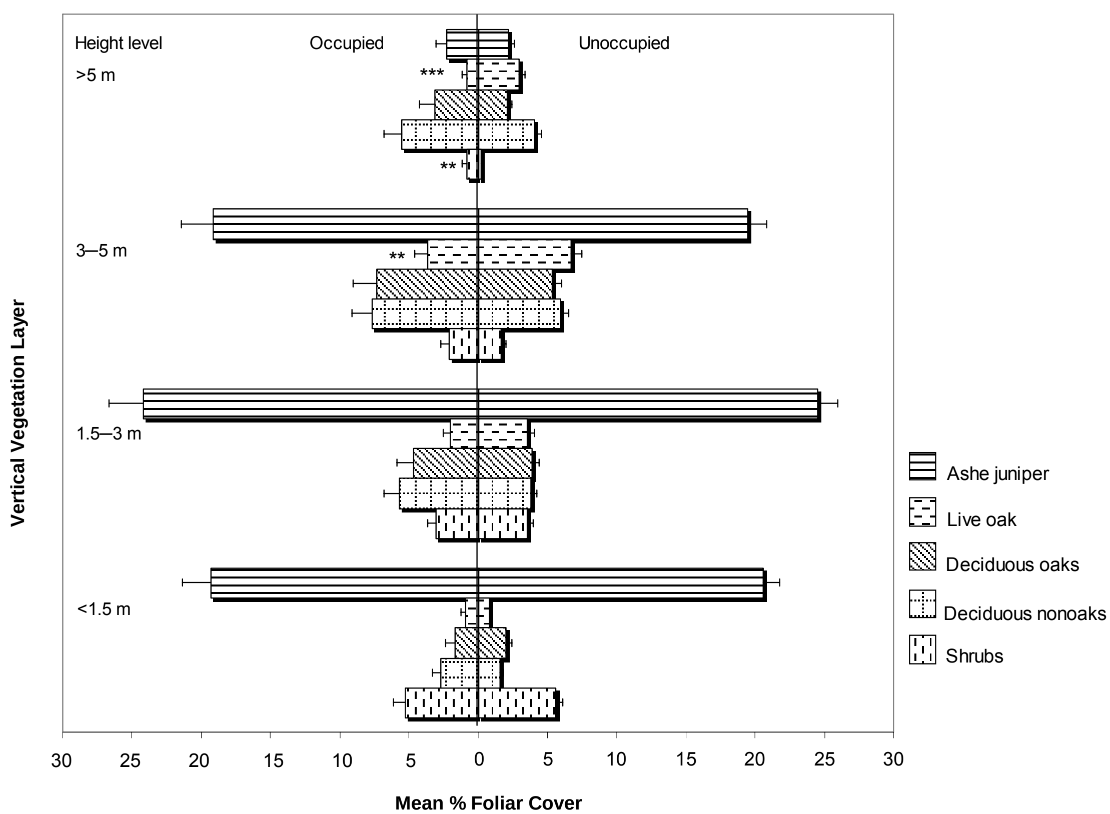

Fig. 19. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the Bell's vireo in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

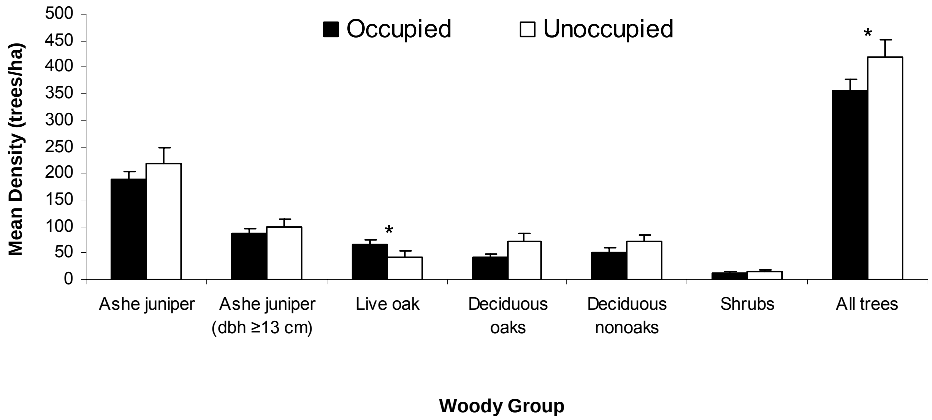

Fig. 20. Mean (+SE) density (trees/ha) by woody plant group for occupied and unoccupied sites of the painted bunting, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

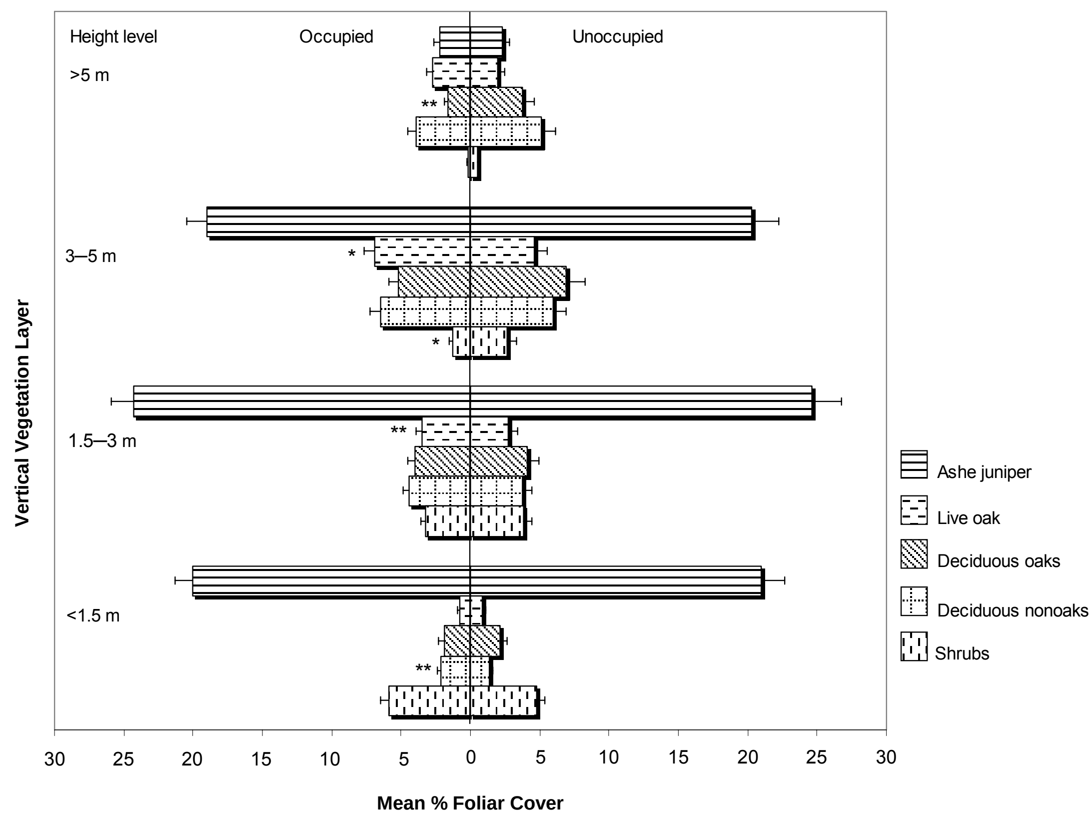

Fig. 21. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the painted bunting in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

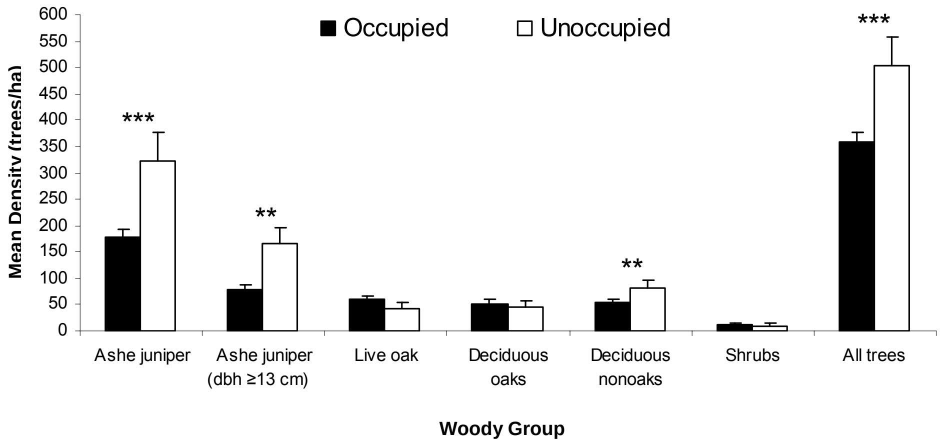

Fig. 22. Mean (+SE) density (trees/ha) by woody plant group for occupied and unoccupied sites of the brown-headed cowbird, from 376 sites in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$. All trees category excludes Ashe juniper (dbh ≥13 cm).

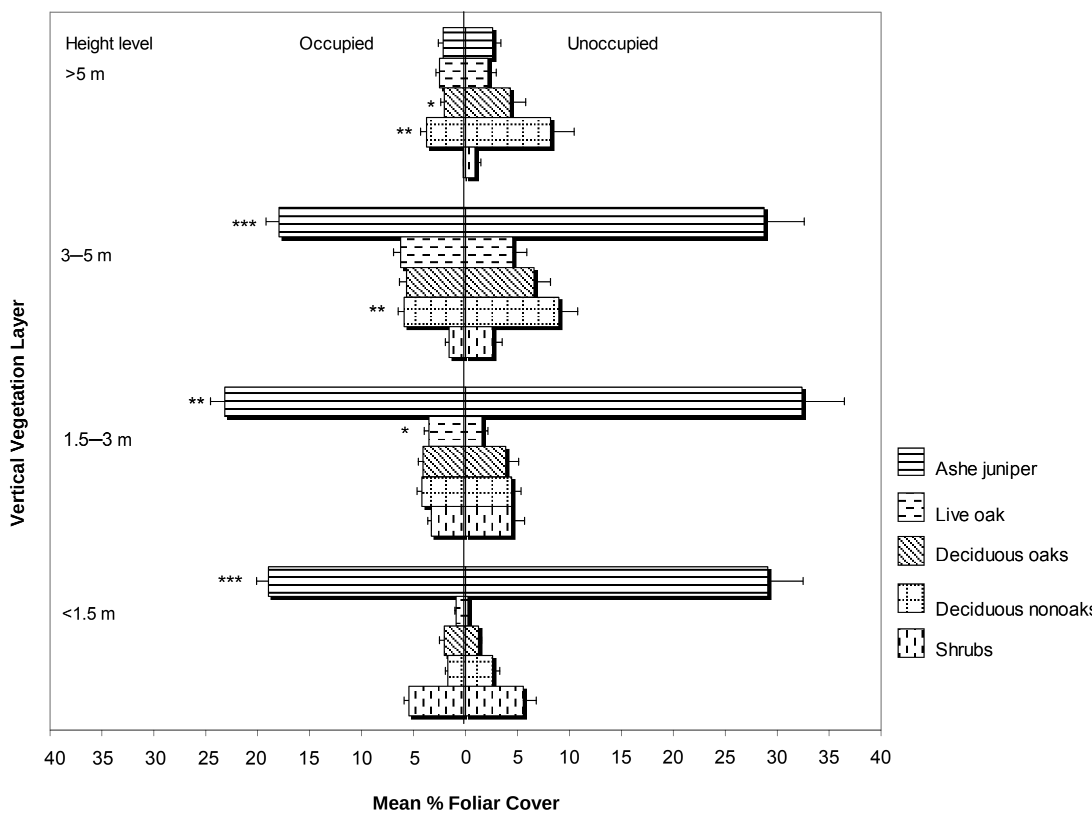

Fig. 23. Mean (+SE) % foliar cover by vertical vegetation layer at occupied and unoccupied sites of the brown-headed cowbird in the Leon River Watershed, Texas. Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$.

microsites than at occupied sites (Table 4, Fig. 10). Black-capped vireo microsites also had lesser amounts of juniper cover above the midstory canopy (>3 m).

Golden-cheeked warbler microsites tended to have a lower density of live oak trees. Ground layer cover of bare ground, forbs, and grasses were less abundant in occupied sites than in unoccupied sites for the golden-cheeked warbler (Table 5). Furthermore, these 3 ground cover classes were also less abundant in microsites than in occupied sites. Although litter and rock cover were higher in golden-cheeked warbler occupied sites than unoccupied sites, this trend did not continue into microsites.

Habitat Models

Occurrence of the black-capped vireo was positively associated with Low Stony Hill ecological sites, and with increasing low-growing (<1.5 m) hardwood cover vegetation (Table 7, Fig. 24).

The model with the highest McFadden's rho squared (i.e., better fit) was the golden-cheeked warbler model with 4 variables included (Table 7). Golden-cheeked warbler probability of occurrence increased with decreasing midstory canopy of deciduous nonoaks cover (1.5–3 m), increasing FHD, and increasing juniper tree density (≥13 cm dbh) (Fig. 25). Species occurrence was also positively associated with Low Stony Hill and Steep Adobe ecological sites.

For the northern bobwhite, 4 variables were included in the final habitat model for predicting species occurrence (Table 7). Northern bobwhite occurrence was positively associated with low-growing (<1.5 m) hardwood cover, and negatively associated with mid to upperstory canopy cover (3–5 m) of deciduous oaks, overstory canopy cover of deciduous nonoaks (>5 m), and FHD (Fig. 26).

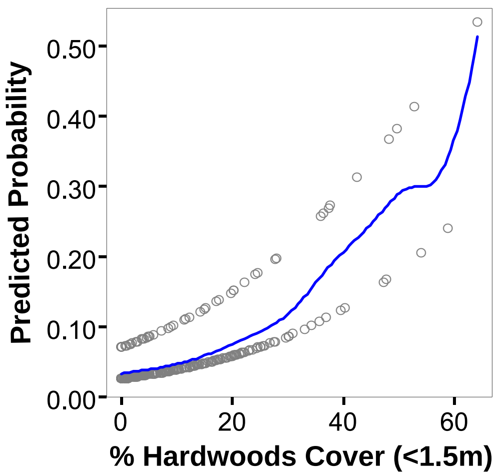

Fig. 24. Predicted probability of occurrence in relation to % hardwood cover (<1.5m) for the black-capped vireo in the Leon River Watershed, Texas. Curve generated using a smoother.

The final white-eyed vireo habitat model included 1 variable with a negative coefficient and 4 variables with positive coefficients. Probability of occurrence for the white-eyed vireo increased with increasing deciduous nonoaks cover, increasing low-growing (<1.5 m) hardwood cover, increasing ground layer of litter cover, and decreasing live oak cover (Fig. 27). The model also suggested that the white-eyed vireo is positively associated with Clay Loam and Loamy Bottomland ecological sites.

The Bell's vireo habitat model created had the lowest McFadden's rho squared value of any of the 7 species models. The model indicated that the probability of

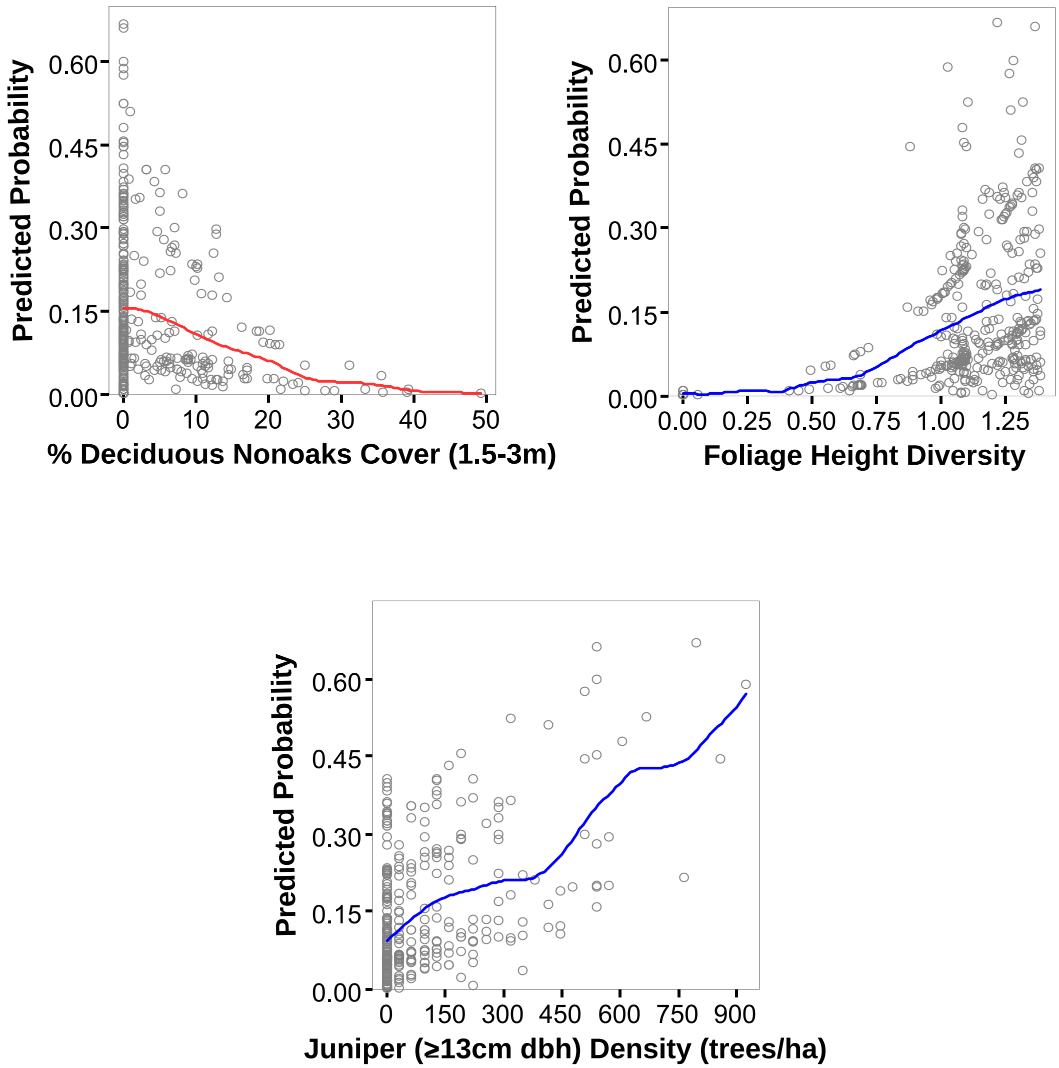

Fig. 25. Predicted probability of occurrence in relation to 3 different continuous predictor variables for the golden-cheeked warbler in the Leon River Watershed, Texas. Curve generated using a smoother.

Table 7. Results of stepwise logistic regression analyses for species presence/absence from 376 sites, in the Leon River Watershed, Texas. Variables are listed in the order they were kept in the model.

Species	Variable	Coefficient	Wald χ^2	*P*	R^2	ROC Value
Northern bobwhite	Intercept	0.076	0.037	0.847	0.098	0.702
	Hardwoods cover (<1.5 m height)	0.040	14.885	< 0.001		
	Deciduous oaks cover (3–5 m height)	-0.035	5.278	0.022		
	Deciduous nonoaks cover (>5 m height)	-0.048	6.514	0.011		
	Foliage height diversity index	-1.015	7.149	0.008		
White-eyed vireo	Intercept	-2.397	49.305	< 0.001	0.113	0.714
	Ecological sites2[a]	0.968	7.952	0.005		
	Live oak cover	-0.029	6.744	0.009		
	Deciduous nonoaks cover	0.018	5.564	0.018		
	Hardwoods cover (<1.5 m height)	0.031	8.126	0.004		
	Litter cover	0.019	11.043	0.001		
Bell's vireo	Intercept	-1.257	86.903	< 0.001	0.038	0.587
	Live oak cover (>5 m height)	-0.086	5.349	0.021		
	Shrubs cover (>5 m height)	0.150	6.505	0.011		
Black-capped vireo	Intercept	-3.633	105.501	< 0.001	0.087	0.668
	Ecological sites4	1.051	4.380	0.036		
	Hardwoods cover (<1.5 m height)	0.042	7.948	0.005		
Golden-cheeked warbler	Intercept	-6.086	22.494	< 0.001	0.164	0.778
	Ecological sites5	1.473	19.334	< 0.001		
	Deciduous nonoaks cover (1.5–3 m height)	-0.085	6.204	0.013		
	Foliage height diversity index	3.109	8.349	0.004		
	Ashe juniper tree density (≥13 cm dbh)	0.002	5.475	0.019		
Painted bunting	Intercept	1.181	50.628	< 0.001	0.045	0.618
	Deciduous oaks cover (>5 m height)	-0.051	8.459	0.004		
	Shrubs cover (3–5 m height)	-0.053	6.437	0.011		
	Rock cover	-0.028	8.558	0.003		
Brown-headed cowbird	Intercept	2.555	113.638	< 0.001	0.068	0.700
	Deciduous nonoaks cover	-0.026	10.651	0.001		
	Ashe juniper tree density (≥13 cm dbh)	-0.003	14.325	< 0.001		

[a] Categorical variable, coded 1 for ecological site(s) preferred by species (based on univariate test), coded 2 for all other sites.

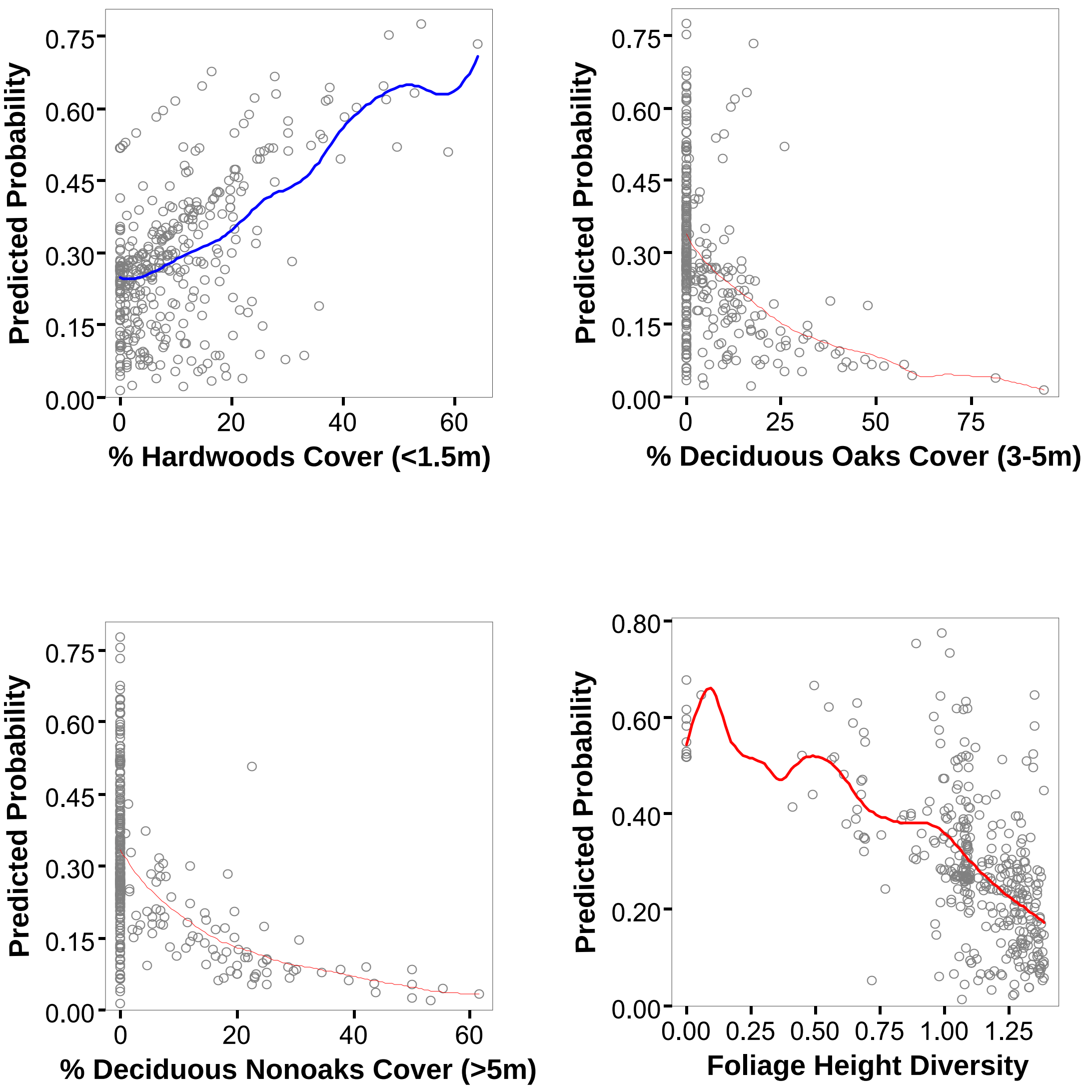

Fig. 26. Predicted probability of occurrence in relation to 4 different continuous predictor variables for the northern bobwhite in the Leon River Watershed, Texas. Curve generated using a smoother.

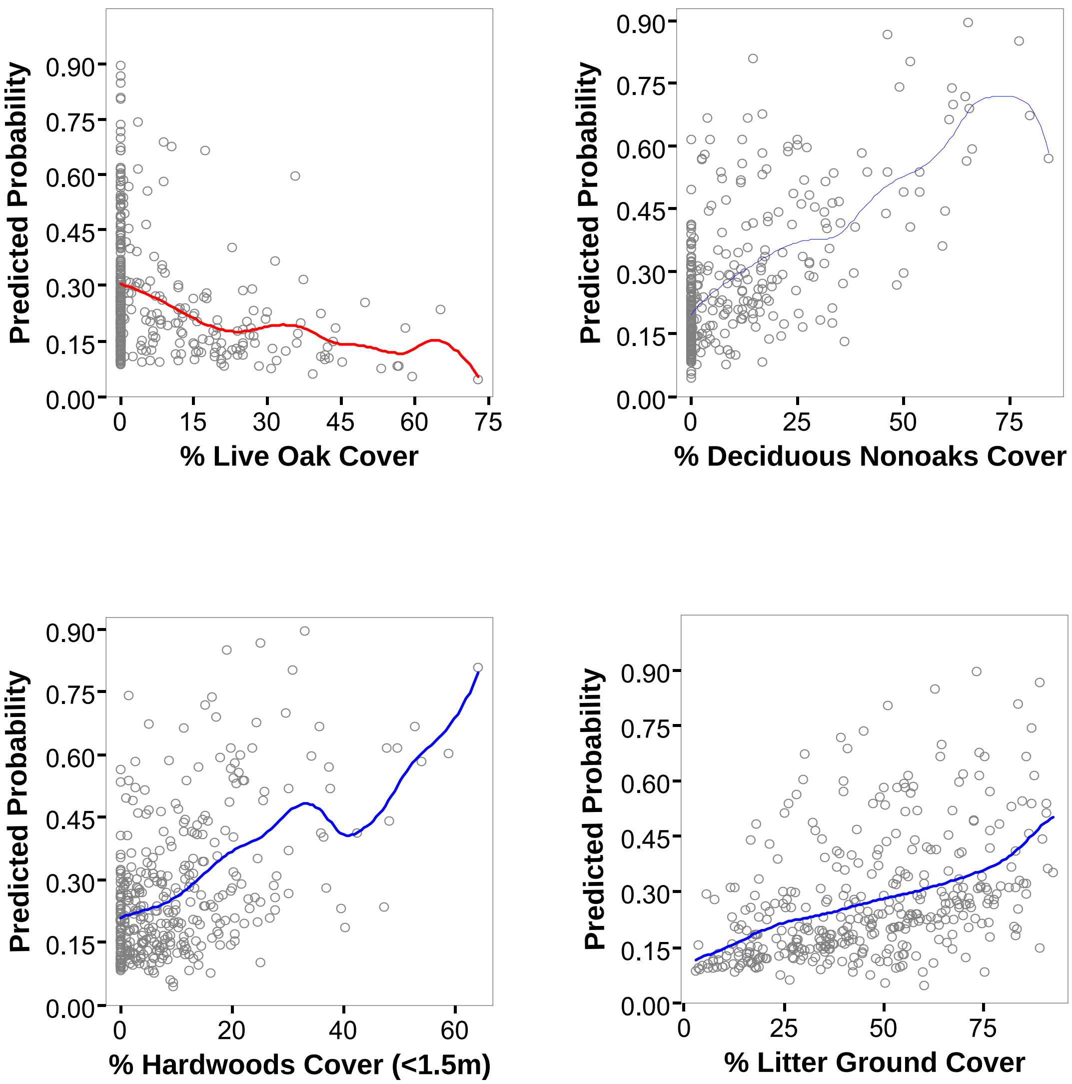

Fig. 27. Predicted probability of occurrence in relation to 4 different continuous predictor variables for the white-eyed vireo in the Leon River Watershed, Texas. Curve generated using a smoother.

occurrence increased with increasing overstory canopy (>5 m) of shrub cover, and decreasing overstory canopy (>5 m) of live oak cover (Fig. 28).

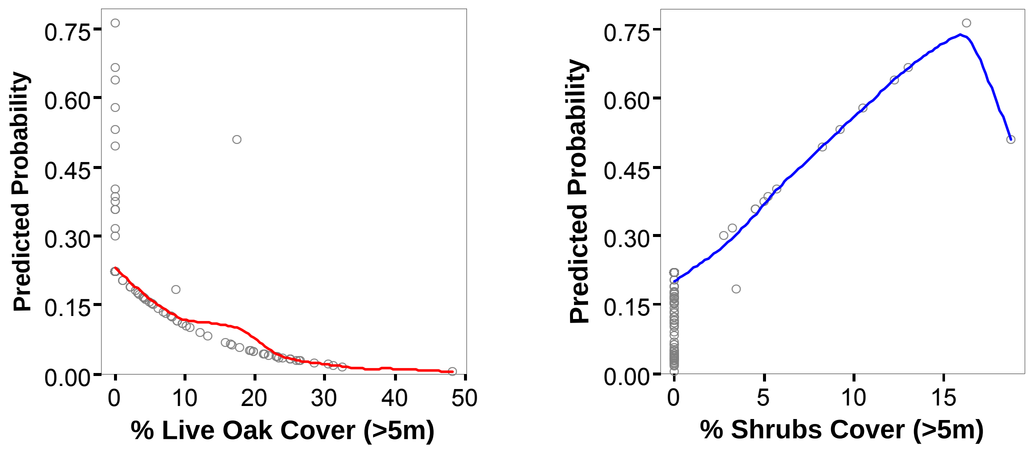

Fig. 28. Predicted probability of occurrence in relation to 2 different continuous predictor variables for the Bell's vireo in the Leon River Watershed, Texas. Curve generated using a smoother.

The final painted bunting model only included 3 variables. Painted bunting occurrence increased with decreasing overstory canopy of deciduous oaks cover (>5 m), decreasing upperstory canopy cover of shrubs (3–5 m), and decreasing ground layer of rock cover (Fig. 29).

For the brown-headed cowbird, only 2 variables (negative coefficients) were included in the final model. The model suggested that probability of occurrence increased as deciduous nonoaks cover and juniper tree density (≥13 cm dbh) decreased (Fig. 30). Two similar variables were selected for just the female brown-headed cowbird habitat model; increasing probability of occurrence was associated with decreasing cover of deciduous nonoaks, and decreasing density of juniper trees.

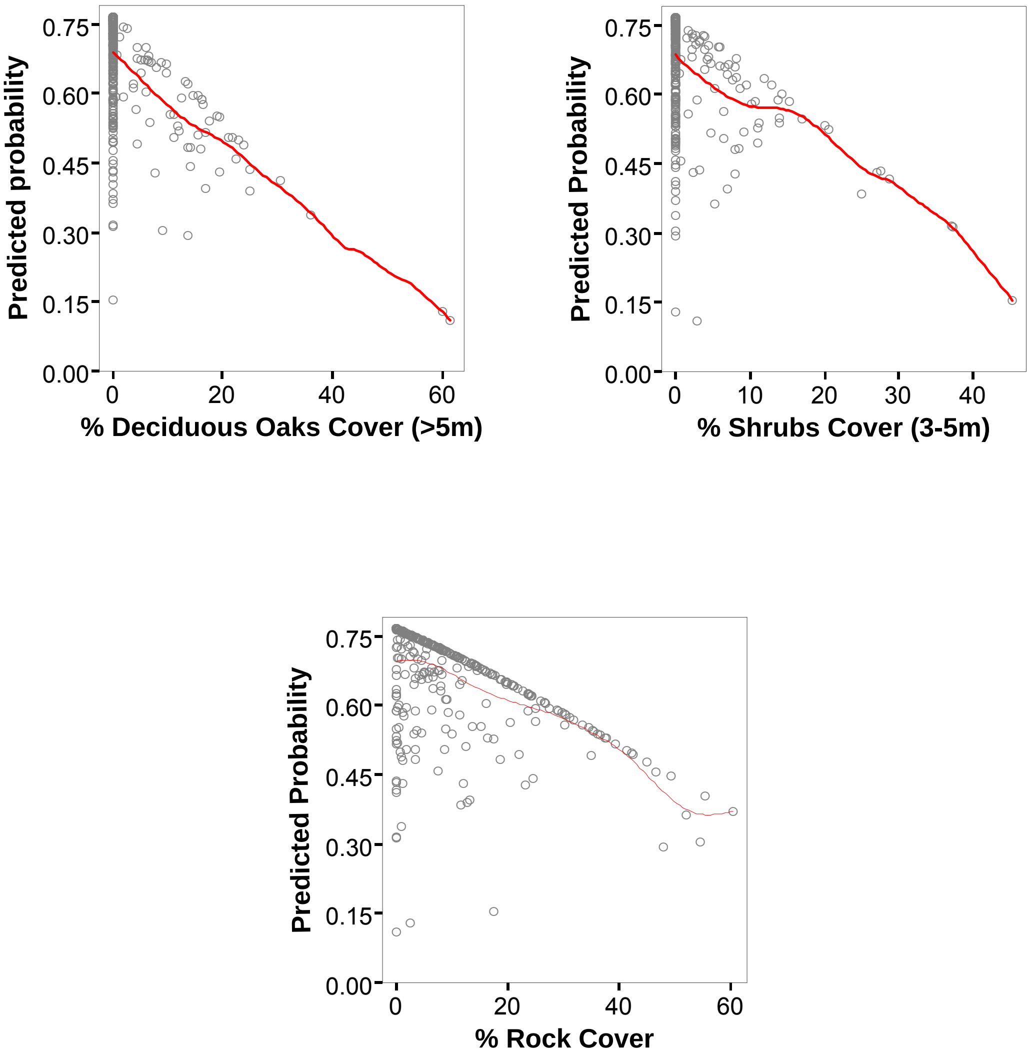

Fig. 29. Predicted probability of occurrence in relation to 3 different continuous predictor variables for the painted bunting in the Leon River Watershed, Texas. Curve generated using a smoother.

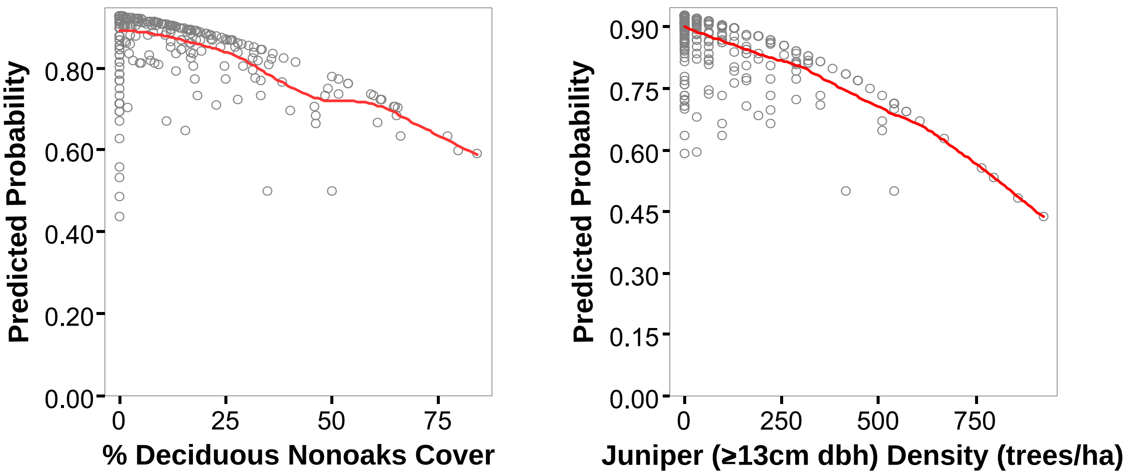

Fig. 30. Predicted probability of occurrence in relation to 4 different continuous predictor variables for the brown-headed cowbird in the Leon River Watershed, Texas. Curve generated using a smoother.

For comparison purposes habitat models were also generated using only the 6-minute counts, resulting in mostly the same variables, as those presented above, being selected for most species. The habitat models based on the 6-minute counts are presented in Appendix E. However, the variables selected for the black-capped vireo appear not to be biologically relevant; instead the selected variables may be a result of the very low sample size (only 8 sites occupied).

DISCUSSION

Species-habitat Relationships

The study of species-environment relations is based on the premise that predictable relations exist between the occurrence of a species and specific characteristics of its habitat (Heglund 2002, Wiens 2002). Morrison and Hall (2002:51) defined habitat as “the physical space within which the animal lives, and the abiotic and biotic entities…in that space”. Thus, efforts to predict species occurrence in space and time requires one to investigate and analyze its response to environmental variables (Wiens 1989). The most common response variable is the presence/absence of a species which is used to predict occurrence within its range (Heglund 2002). A species distribution pattern results from “decisions” made by individual birds when seeking out breeding or wintering areas (Wiens 1989:293). Hutto (1985:458) described the process of habitat selection by an animal as a hierarchical series of decisions occurring at different scales of the environment. Hutto (1985) suggested that an animal chooses a geographic location, followed by a particular habitat, then a microhabitat.

When studying species-habitat relationships, the issue of scale is very important (Wiens 1989). Wiens (2002:746-747) addresses 3 issues of scale which are problematic in applied ecology: (1) species patterns that are evident at a fine scale may disappear at a coarser scale (2) scientists often ignore consideration of scale (grain and extent) differences within or between studies, and (3) it is difficult to extrapolate results to different scales from the original scale of a study.

The primary tool for evaluating species-habitat relationships has been the use of models (Wiens 2002). Models are used to predict species diversity, distribution patterns, and changes due to habitat modifications (Heglund 2002, Wiens 2002). Models should be developed using the most appropriate scale of analysis, to be commensurate with "the scale that we wish to use in applying our results to management purposes" (Morrison et al. 1998:141). Implementation of rational management systems depends on our abilities to understand species-habitat relationships (Wiens and Rotenberry 1981). This is especially true for the conservation of disturbance-dependent birds many of which are listed as threaten or endangered (Hunter et al. 2001). Various authors have reported the decline of migratory bird species (Askins et al. 1990, 1993, Rappole and McDonald 1994, and Hunter et al. 2001). Disturbance-dependent species are those whose habitat is maintained by some form of disturbance, such as fire, and grazing (Hunter et al. 2001:441). Hunter et al. (2001:453) suggested that implementation of "managed disturbances" such as prescribed fires, and brush management (mechanical thinning) would benefit disturbance-dependent birds.

Within the context of applied ecology, I analyzed species-habitat relationships for a select group of bird species in the Leon River Watershed, Texas. For 2 endangered species I analyzed occurrence at 2 different scales, sites and microsites. Model development at these finer scales allow for the evaluation of how individuals react to changes in local variables such as vegetation structure (e.g., vegetation cover, tree density), an approach that's appropriate when the goal is to develop management objectives for localized bird populations (Morrison et al. 1998). Because broad-scale (landscape level) comparisons were not made, any scale-dependent patterns existing at this level would not be discovered (Wiens et al. 1987). However, as Wiens et al. (1987:145) recommended "If one is interested in how birds select, use, and partition habitats, a broad-scale approach is too coarse and general to reveal much about what is actually going on, and a more intensive, local perspective is required".

Distance to Fort Hood

Populations of black-capped vireo and golden-cheeked warblers occurring within Fort Hood have been under active monitoring, habitat management, and cowbird control, in an effort to maintain and enhance both species' populations. It appears that these efforts have been successful, as significant increases in the golden-cheeked warbler population has been documented on Fort Hood from 1992-2002 (Sterling Graber 2002). Similarly, black-capped vireo populations in Fort Hood had been increasing for several years before leveling off (Cimprich 2002). Because of Fort Hood's location within the watershed, I wanted to examine whether distance to Fort Hood was a possible factor in the observed presence patterns of black-capped vireos or golden-cheeked warblers in this study. Upon first inspection, it appeared that black-capped vireo and golden-cheeked warbler detections occurred closer to Fort Hood Military. However, a closer rudimentary look at both black-capped vireo and golden-cheeked warbler detection patterns outside the base appears to suggest that is not what is driving site occupancy in my study area. The apparent pattern may be due to more suitable habitats occurring in Coryell County than in Hamilton County. Generally the points surveyed in Hamilton County occurred in more open areas interspersed with second growth juniper. It's likely that lack of suitable habitat may be the driving variable determining site occupancy, although other confounding variables should also be considered. Thus, an opportunity for further study would be to investigate if some areas serve as “source” habitats and others as “sink” habitats within the spatially heterogeneous environment of the Leon River Watershed. Source-sink models examine how different local birth and death rates in different areas affect equilibrium population levels (Pulliam 1988).

Habitat Models

The habitat models developed for the 7 selected species generally agree with the natural history descriptions associated with each respective species. For most of the 7 species, the variables included in the final habitat model could be explained with knowledge of the vegetation structure and woody plant groups (i.e., growth forms) typically associated with each species habitat. Many of the variables selected described specific layers of the vertical vegetation profile. Interestingly, the categorical variable Ecological Site, when selected, was the first variable to be kept during model development, which may indicate that a species is strongly associated with certain vegetative composition that’s correlated with a given ecological site. Relatively few studies have made use of USDA defined ecological sites as a predictor variable in species occurrence. Schlefsky (2003) found some positive associations between ecological sites and abundance and diversity of a small mammal and herpetofauna community in West Texas.

Black-capped vireo occupied sites were characterized by low-growing hardwood vegetation. At the microsite level, the black-capped vireo appears to prefer sparser juniper cover than that generally available above the lowstory canopy (>1.5 m). More specifically, increasing low-growing (0–1.5 m) hardwood vegetation appears to be important in predicting black-capped vireo occurrence. These results agree with those of others (e.g., Graber 1961, Grzybowski et al. 1994). Grzybowski et al. (1994) reported that male black-capped vireo breeding territories occurred in areas with low deciduous vegetation, and low densities of juniper. In this study, the black-capped vireo appears to respond to habitat at a finer scale than the golden-cheeked warbler. Deciduous oaks cover and tree density, and upperstory canopy cover of juniper appear to be less in microsites than in occupied black-capped vireo sites.

Occupied black-capped vireo sites and microsites were positively associated with Low Stony Hill ecological sites. These ecological sites are primarily composed of shallow and very shallow soils, which are underlain by limestones or rock outcrops, areas found on “broad plane areas and convex ridgetops” (McCaleb 1985:21). A strong correlation between the Fredericksburg limestones and occupied black-capped vireo habitats has been suggested (C. W. Sexton, unpublished data). The varied edaphic conditions found in Fredericksburg and other limestones of the Late Cretaceous results in the irregular distribution of plant species interspersed with open spaces, forming suitable black-capped vireo habitat (Graber 1961, Grzybowski et al. 1994).

Golden-cheeked warbler occupied sites were characterized by juniper-oak woodlands with little shrub or live oak cover. The habitat model for the golden-cheeked warbler indicated that occupied sites were more likely to be found on Steep Adobe and Low Stony Hill ecological sites with higher juniper tree density, higher FHD, and a decreasing midstory canopy cover of deciduous nonoaks. The golden-cheeked warblers in this study occurred in those same ecological site types identified by Campbell (1995); however, golden-cheeked warblers clearly showed a preference for Steep Adobe sites and Low Stony Hill sites. Steep Adobe sites are characterized by steep slopes (12 to 40%) and canyons, and Low Stony Hill sites are found in upland ridgetops with shallow rocky soils (McCaleb 1985). The preference for habitats occurring in steep slopes and rugged terrain may be an artifact of these sites providing greater protection against the effects of wild fires, or because of the high cost and difficulty associated with brush clearing these steep slopes (U.S. Fish and Wildlife Service 1992:7).

Various researchers have categorized golden-cheeked warbler habitat as consisting of old-growth and mature regrowth juniper-oak woodlands typically occurring in limestone hills and canyons (Pulich 1976, Wahl et al. 1990, and U.S. Fish and Wildlife Service 1992). Wahl et al. (1990) suggested that greater variability in tree heights, greater density of deciduous oaks, and greater average tree height were associated with higher densities of golden-cheeked warblers. Thus, a preference for variability in vertical vegetation structure supports the finding of increasing FHD as a driving variable in predicting golden-cheeked warbler occurrence in this study. The observed patterns of ground layer cover classes found in these juniper-oak woodlands agree with the observations of others. Yager and Smeins (1999) documented that understory vegetation in a juniper-oak savanna is characterized by less herbaceous (grasses and forbs) vegetation with an increasing juniper leaf litter accumulation. As juniper is primarily found in calcareous, shallow rocky soils formed from limestone parent materials (Smeins et al. 1997:33), it's no surprise golden-cheeked warblers occupied sites with higher rock and litter cover. Ground cover classes at the microsites showed differences from occupied sites (with trends in the same direction as those from unoccupied to occupied sites). This may result from a more closed canopy of juniper and oaks occurring at the microsites. Vegetation cover and tree density were higher at microsites than occupied sites, but not statistically significant.

The variables selected for the northern bobwhite habitat model are fairly easy to interpret. Many authors (e.g., see Brennan 1999:5) have found that the northern bobwhite requires early successional habitats occurring in any number of vegetation types. The model suggested that the probability of occurrence in an area increased as both the upperstory canopy cover of deciduous nonoaks and midstory canopy cover of deciduous oaks decreased. Similarly to the black-capped vireo and white-eyed vireo, northern bobwhite showed a positive association with increasing low-growing hardwood vegetation. This preference for shrubby areas (no mid to upper levels canopy cover) is further supported by the inclusion in the model of a decreasing FHD as associated with northern bobwhite presence. This is in contrast to the golden-cheeked warbler, where an increasing FHD was associated with its presence.

The White-eyed vireo habitat model suggested that probability of occurrence was associated with increasing deciduous nonoaks cover, increasing low-growing hardwood cover, increasing ground layer cover of litter, and decreasing live oak cover. The model also suggested a positive association with Clay Loam and Loamy Bottomland ecological sites, both of which have a high cover of deciduous nonoaks and shrubs. Habitat characteristics for the white-eyed vireo vary across its breeding range (Hopp et al. 1995); but generally, habitat in Texas has been described as composed of low growing vegetation, or thickets, with a high diversity of shrub species (Conner et al. 1983).

Habitat models for the species considered to be more habitat generalists (Bell's vireo, painted bunting, and brown-headed cowbird) when evaluated for model fit had the lowest McFadden's Rho-squared values (Table 7). The variables selected for the Bell's vireo and painted bunting described the mid to upper canopy levels. There is very little data quantifying the breeding habitat for the painted bunting (Lowther et al. 1999). Oberholser (1974) described the habitat in Texas as consisting of semi-open country with scattered bushes and trees, areas with trees not too coarse or not too dense. The 2 variables selected for the brown-headed cowbird described the broad characteristic of deciduous nonoaks cover, and juniper tree density (both negatively associated with occurrence). Both these variables, but especially juniper tree density, reflects the general habitat preferences associated with this species, as preferring areas with low or scattered trees among grassland vegetation (Lowther 1993). Interestingly, juniper tree density was also selected as a predictor variable for the golden-cheeked warbler but with a positive coefficient. Magness (2003) observed similar trends; in her study, the golden-cheeked warbler occurred in areas with more juniper cover at both local and landscape scales, while the brown-headed cowbird exhibited the opposite trend (less juniper cover) at both scales. The Bell's vireo, painted bunting, and brown-headed cowbird had relatively low numbers of variables (≤16) for which significant differences were detected when comparing occupied sites and unoccupied sites. All the other species (excluding black-capped vireo) had relative high numbers of variables (≥25) which were found to differ. The exception of the black-capped vireo may be due to the relatively low number of detections made in the study.

Model Performance

The amount of variation explained by each model was somewhat poor. Model building for uncommon species may be problematic because of incomplete or quasicomplete separation in the logistic regression procedures (Hosmer and Lemeshow 2000). Developing strong habitat models for very common species such as the brown-headed cowbird or painted bunting is also difficult because they tend to be fairly general in their habitat associations, as was the case in my study, where they occurred in a wide variety of habitats. Mitchell et al (2001) found that model fit, for the species they studied, tended to be poor for species that were present at few sites (n<20) as well as for species that were present at many sites (n>100). In this study black-capped vireos occupied only 21 sites, while 4 other species occupied <100 sites each. Hensher and Johnson (1981) considered a rho-squared value between 0.2 and 0.4 to be very satisfactory. Most of the models had R^2 values below 0.10 (Table 7). In terms of discrimination capacity, 4 of 7 models had acceptable discrimination meaning the models could discriminate between occupied and unoccupied sites ≥70% of the time (Pearce and Ferrier 2000, Hosmer and Lemeshow 2000). Although these models were not validated with independent data, they can still be useful to resource managers, as the models provide a preliminary examination of important controlling variables (Young and Hutto 2002). The inclusion of interactions between variables, squared variables

(Hosmer and Lemeshow 2000), and landscape-level variables (Wiens et al. 1987) may have improved model performance. However, James and McCulloch (2002:465) suggest that for a model to be useful in making management decisions, model predictions “should focus on analyses of those environmental factors that are directly limiting and those that can be manipulated.” Consequently, I was interested in developing parsimonious models that could easily be interpreted under management scenarios, thus I considered only main effects in the models (Johnson et al. 2002).

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

This study documented site occupancy of 7 selected species in the Leon River Watershed, to serve as a baseline inventory from which results of future brush management treatments may be compared. I identified potential black-capped vireo and golden-cheeked warbler habitats found on private lands within the watershed. This provides an opportunity for natural resource managers to work with interested landowners in implementing appropriate brush management systems. The habitat models developed should provide a preliminary frame of reference for use in maintaining or creating suitable habitat composition for these species of special concern.

The models developed generally were in agreement with the niche-gestalt descriptions for these species. The variables that seem to be driving site occupancy are variables that describe overall vegetation structure. A couple of variables that appear to be important in determining site occupancy for several species, and that can be managed for, are cover of low-growing non-juniper vegetation and juniper tree density (≥13 cm dbh). Historically, areas with low deciduous woody vegetation (occurring in a mixed-oak savanna) developed in the presence of moderate grazing by large herbivores (e.g., American bison [*Bison bison*]) and periodic wild fires (Smeins et al. 1997). Fire suppression and overgrazing has allowed for the conversion of mixed-oak savannas into dense juniper stands (Fonteyn et al. 1988, Smeins et al. 1997). Thus an approach to conservation management for several of these species dependent on early successional habitats involves the creation or maintenance of low deciduous woody vegetation. This can be accomplished through the implementation of prescribed fire regimes, and moderate grazing stocking rates (Campbell 1995). Depending on the level of woody encroachment, mechanical removal of second-growth juniper may be warranted before the implementation of prescribed fires. Similar approaches have been implemented to create or maintain black-capped vireo habitat in several managed lands such as at the Kerr Wildlife Management Area (O'Neal et al. 1996), and Fort Hood Military base (Grzybowski 1995), both located in Texas. For golden-cheeked warbler habitat, managers can identify potential habitat probably occurring in Low Stony Hill and Steep Adobe ecological sites. If these areas consist of shrubby second growth juniper, they can be enhanced through the selective thinning of juniper. The thinning would allow remaining trees to mature faster, and also for the establishment of deciduous oaks (U.S. Fish and Wildlife Service 1992, Campbell 1995). Conversely these areas may already support mature oak-juniper woodlands in which case they can be protected.

Another conservation component would be the implementation of a cowbird management program to reduce cowbird parasitism rates as contemplated under the LRRP (T. J. Cloud. 2003. Biological Opinion, U.S. Fish and Wildlife Service, Arlington, Texas, USA). Since the black-capped vireo and golden-cheeked warbler are relatively uncommon in the study area, the cowbird control program could be made more effective by targeting these isolated habitat patches (i.e., occupied sites) of the black-capped vireo and golden-cheeked warbler (Hayden et al. 2000).

Future Work

Primarily, this baseline study will assist in another phase of the LRRP; a post-treatment study to provide a means for adequately evaluating any changes in habitat use by the species of interest resulting from a brush management program. The pre- and post-treatment studies of habitat and species populations will serve to provide operational certainty to landowners, as well as assurances to resource managers that important wildlife habitats in the watershed are more likely to be maintained, and ultimately enhanced.

In this study species presence/absence was correlated with vegetation variables at site-specific scales. Thus a possible next step would be to conduct landscape scale analyses such as quantifying the proportion of various habitat types within a standardized area surrounding point counts in an effort to obtain an estimate of the relationship between landscape composition and site use by selected species. The measured vegetation structure and composition at each site can be used to classify images created from remote sensing data to quantify the landscape variables. Landscape level variables appear to be important in predicting golden-cheeked warbler occurrence. Magness (2003) reported that golden-cheeked warblers were associated with an increasing cover of juniper, oak, and mix cover at the landscape scale, and these landscape scale variables were more highly significant than local scale variables. Thus, a landscape level analysis should provide natural resource managers with information needed to develop appropriate guidelines for identifying specific areas to focus their management efforts. The resulting spatially-explicit models should provide a means for evaluating the effects of brush management practices on species presence before and after brush removal, and for predicting species occurrence across the landscape.

Another next step could be to monitor cowbird parasitism rates for the black-capped vireo and golden-cheeked warbler in their relatively few occupied sites documented during this study. One possible goal would be to compare the reproductive success of these populations to those of Fort Hood which have been under intensive cowbird management for several years.

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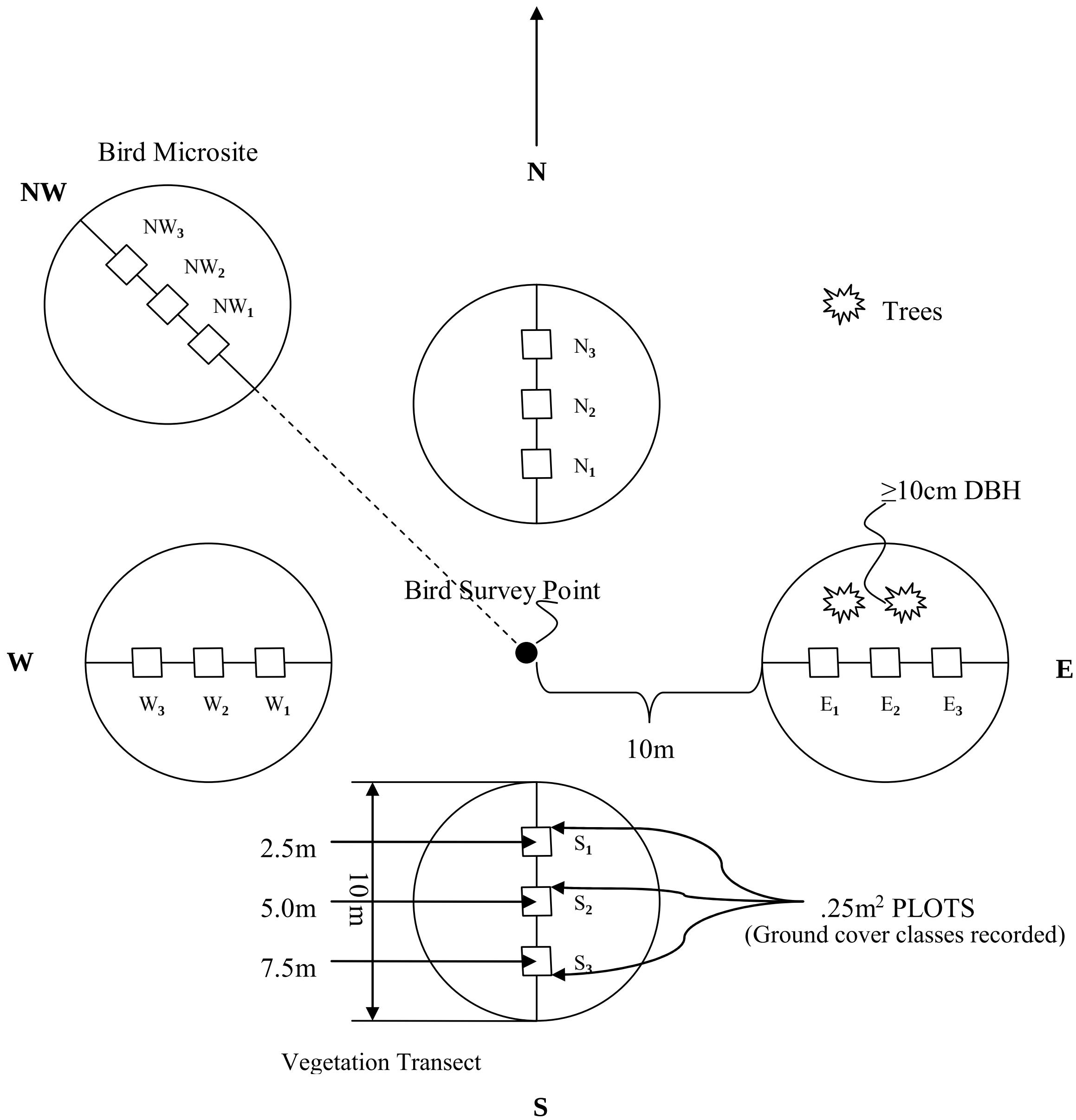
APPENDIX A

Diagram of vegetation survey plot.



APPENDIX B

Number of individuals detected and number of occupied sites by species from point counts of different length, at 378 points following 3 survey visits, in the Leon River Watershed, Texas.

	Count length (min)					
	6		12[a]		12 plus[b]	
Species	Individuals (n)	Sites Occupied (n)	Individuals (n)	Sites Occupied (n)	Individuals (n)	Sites Occupied (n)
Northern bobwhite	148	77	221	101	276	110
White-eyed vireo	107	80	137	97	145	102
Bell's vireo	73	63	92	77	95	79
Black-capped vireo	10	8	22	19	26	21
Golden-cheeked warbler	60	40	75	50	82	52
Painted bunting	350	214	441	247	450	251
Brown-headed cowbird	678	269	1148	323	1221	328

[a] Although the survey protocol allowed for the possibility of a point count lasting less than 12 minutes, 94.7% of visits had a complete 12-minute survey period.
[b] includes observations made as observer approached or left point location.

APPENDIX C

Mean % ground cover class by bird species occupancy, from 376 sites in the Leon River watershed, Texas.

	Northern bobwhite				White-eyed vireo				Bell's vireo			
	Occupied (*n* = 110)		Unoccupied (*n* = 266)		Occupied (*n* = 102)		Unoccupied (*n* = 274)		Occupied (*n* = 79)		Unoccupied (*n* = 297)	
Ground cover	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	11.8	1.1	10.3	0.6	10.2	1.0	11.0	0.6	12.3	1.4	10.4	0.6
Rock	8.4	1.0	9.5	0.7	9.6	1.1	9.0	0.7	9.7	1.2	9.0	0.7
Litter	39.3***[a]	2.3	48.2	1.3	51.6***	2.1	43.3	1.3	42.9	2.4	46.3	1.3
Forbs	9.5*	0.8	8.1	0.5	6.6**	0.7	9.2	0.5	8.7	0.8	8.4	0.5
Grass	30.2***	2.1	23.1	1.1	20.4***	1.5	26.9	1.2	25.9	2.2	24.9	1.1

Continued.

Ground cover	Painted bunting				Brown-headed cowbird				Total	
	Occupied (n = 250)		Unoccupied (n = 126)		Occupied (n = 326)		Unoccupied (n = 50)		(n = 376)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	11.1	0.7	10.2	0.9	11.3***	0.6	6.9	1.1	10.8	0.5
Rock	8.1*	0.6	11.1	1.2	9.1	0.6	9.2	1.5	9.1	0.6
Litter	45.8	1.4	45.1	2.0	44.3***	1.2	53.8	3.2	45.6	1.2
Forbs	9.1**	0.5	7.3	0.7	8.6	0.5	8.0	1.2	8.5	0.4
Grass	25.1	1.2	25.2	1.7	25.8	1.1	21.2	2.5	25.1	1.0

[a] Significant at *$P \leq 0.10$, **$P \leq 0.05$, or ***$P \leq 0.01$ when comparing occupied versus unoccupied sites (Mann-Whitney tests).

APPENDIX D

Individual explanatory variables showing a significant difference between occupied and unoccupied sites for each of 7 avian species by 6-minute and 12-minute plus (includes pre- and post-survey detections) point counts, from 378 survey sites in the Leon River Watershed, Texas.

	NOBO[a]		WEVI		BEVI		BCVI		GCWA		PABU		BHCO	
Habitat variable	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min
Foliar cover (%)														
Ashe juniper	---	---		++					+++	+++				--
Live oak		++	--	--	-	--			--	-				
Deciduous oaks	--	---	+++	++					+++	+++				
Deciduous nonoaks			+++	+++				++					-	-
Shrub	++	+	+++	++						-			-	
Hardwoods (<1.5 m)	+++	++	+++	+++				++						
Hardwoods (<3 m)			+++	++				+++						
Ashe juniper (>3 m)	---	---		+					+++	+++			-	---
Ashe juniper1[b]	---	---							+++	+++			--	---
Ashe juniper2	---	---							+++	+++				--
Ashe juniper3	---	---		+					+++	+++			-	---
Ashe juniper4			+	++					+++	+++				
Live oak1	++	+							--	--				
Live oak2		-	--	-					-	--		++	++	+
Live oak3		++	---	--	--	--						+		
Live oak4					--	---			-		+			
Deciduous oaks1			++	++				+++	+++	+++				
Deciduous oaks2	--	--							++	+++				
Deciduous oaks3	--	---							+++	+++				
Deciduous oaks4	-	---							+			--		-
Deciduous nonoaks1			+++	+++							++	++		
Deciduous nonoaks2			+++	+++				++						

Continued.

Habitat variable	NOBO		WEVI		BEVI		BCVI		GCWA		PABU		BHCO	
	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min	6-Min	12-Min
Deciduous nonoaks3			+++	+++			+	++						--
Deciduous nonoaks4	--	---	+++	+++										--
Shrubs1	+++	++	+++	++						-				
Shrubs2			++	+										
Shrubs3			++	++								-		
Shrubs4		--	+		++	++								
Ground cover (%)														
Bare ground										--				+++
Rock									+++	+++	-	-		
Litter	---	---	+++	+++					+++	+++				---
Forbs	++	+		--					---	---	+	++		
Grass	+++	+++	--	---					--	---				
Tree density (trees/ha)														
Ashe juniper	---	---		+					+++	+++			---	---
Ashe juniper (dbh≥13)	---	---		++					+++	+++			--	--
Live oak		++	--	--		-			---	---		+		
Deciduous oaks	---	---							+++	+++				
Deciduous nonoaks			+++	+++				+					--	--
Shrubs					+++	++	+							
All oaks														
All trees	---	---	+	++					+++	+++		-	---	---

[a] See table 1 for codes of species.

[b] Number following variable name indicates vertical vegetation layer; 1 = 0-1.5 m , 2 = 1.5-3 m, 3 = 3-5 m, and 4 = >5 m height.

+ = species occupied sites have a higher value than unoccupied sites, - = species occupied sites have a lower value than unoccupied sites.
Significant at +/- $P \le 0.10$, ++/-- $P \le 0.05$, or +++/--- $P \le 0.01$ when comparing occupied versus unoccupied sites (Mann-Whitney tests).

APPENDIX E

Results of stepwise logistic regression analyses, using the 6-minute counts, for species presence/absence from 376 sites, in the Leon River Watershed. Variables are listed in the order they were kept in the model.

Species	Variable	Coefficient	Wald χ^2	*P*	R^2	ROC Value
Northern bobwhite	Intercept	-0.526	1.655	0.198	0.111	0.726
	Hardwoods cover (<1.5 m height)	0.047	18.058	< 0.001		
	Deciduous nonoaks cover (>5 m height)	-0.055	5.000	0.025		
	Deciduous oaks tree density	-0.005	4.384	0.036		
	Foliage height diversity index	-0.981	6.029	0.014		
White-eyed vireo	Intercept	-2.427	46.911	< 0.001	0.137	0.736
	Live oak cover	-0.057	12.047	0.001		
	Hardwoods cover (<1.5 m height)	0.035	9.198	0.002		
	Litter cover	0.016	6.454	0.011		
	Deciduous nonoaks tree density	0.004	12.428	< 0.001		
Bell's vireo	Intercept	-1.548	110.445	< 0.001	0.046	0.585
	Live oak cover (>5 m height)	-0.100	4.574	0.032		
	Shrubs cover (>5 m height)	0.171	8.205	0.004		
Black-capped vireo	Intercept	-5.182	51.078	< 0.001	0.184	0.828
	Ecological sites4[a]	2.445	8.059	0.005		
	Live oak cover (0-1.5 m height)	0.184	5.510	0.019		
	Shrubs cover (>5 m height)	0.261	9.184	0.002		
Golden-cheeked warbler	Intercept	-0.355	0.421	0.516	0.105	0.761
	Ecological sites5	-0.1443	15.350	< 0.001		
	Ashe juniper tree density	0.001	7.920	0.005		
Painted bunting	Intercept	0.505	13.773	< 0.001	0.014	0.552
	Rock cover	-0.025	6.819	0.009		
Brown-headed cowbird	Intercept	1.395	38.475	< 0.001	0.058	0.657
	Shrubs cover	-0.024	5.380	0.020		
	Ashe juniper cover (0-1.5 m height)	-0.015	6.535	0.011		
	Live oak cover (1.5-3 m height)	0.073	7.812	0.005		
	Deciduous nonoaks cover (0-1.5 m height)	-0.056	3.886	0.049		

[a] Categorical variable, coded 1 for ecological site(s) preferred by species (based on univariate test), coded 2 for all other sites.

APPENDIX F

Expected and observed frequencies of 7 selected bird species by ecological site, in the Leon River Watershed, Texas

Ecological site	Sites (n)	Northern bobwhite (n = 110)			White-eyed vireo (n = 102)			Bell's vireo (n = 79)		
		observed	expected	χ^2	observed	expected	χ^2	observed	expected	χ^2
Adobe/Shallow	115	42	33.5	2.16	23	31	2.06	20	24	0.67
Clay Loam	35	10	10.2	0.00	16	9.4	4.63**[a]	11	7.3	1.88
Loamy Bottomland	17	3	4.9	0.74	9	4.6	4.21**	6	3.6	1.60
Low Stony Hill	58	17	16.9	0.00	15	15.7	0.03	12	12.1	0.00
Sandy Loam	19	4	5.5	0.41	2	5.1	1.88	3	4	0.25
Steep Adobe	84	14	24.4	4.43**	29	22.7	1.75	19	17.6	0.11
Stony Clay Loam	20	9	5.8	1.77	3	5.4	1.07	0	4.2	4.20**
Other	30	11	8.7	0.61	5	8.1	1.19	8	6.3	0.46

Continued.

Ecological site	Sites (n)	Black-capped vireo (n = 21)			Golden-cheeked warbler (n = 52)			Painted bunting (n = 251)		
		observed	expected	χ^2	observed	expected	χ^2	observed	expected	χ^2
Adobe/Shallow	115	7	6.4	0.06	7	15.8	4.90**	83	76.4	0.57
Clay Loam	35	1	1.9	0.43	4	4.8	0.13	23	23.2	0.00
Loamy Bottomland	17	0	0.9	0.90	1	2.3	0.73	9	11.3	0.47
Low Stony Hill	58	8	3.2	7.20***	15	8	6.13**	33	38.5	0.79
Sandy Loam	19	0	1.1	1.10	0	2.6	2.60	13	12.6	0.01
Steep Adobe	84	5	4.7	0.02	21	11.6	7.62***	55	55.8	0.01
Stony Clay Loam	20	0	1.1	1.10	1	2.8	1.16	15	13.3	0.22
Other	30	0	1.7	1.70	3	4.1	0.30	20	19.9	0.00

Continued.

Ecological site	Sites (n)	Brown-headed cowbird (n = 328)		
		observed	expected	χ^2
Adobe/Shallow	115	105	99.8	0.27
Clay Loam	35	29	30.4	0.06
Loamy Bottomland	17	12	14.8	0.53
Low Stony Hill	58	53	50.3	0.14
Sandy Loam	19	18	16.5	0.14
Steep Adobe	84	70	72.9	0.12
Stony Clay Loam	20	16	17.4	0.11
Other	30	25	26	0.04
Adobe/Shallow	378	328	328	1.41

[a] Significant at $*P \le 0.10$, $**P \le 0.05$, or $***P \le 0.01$.for χ^2 test of association.

APPENDIX G

Mean % foliar cover by woody plant group composition for ecological sites, from 376 survey sites in the Leon River Watershed, Texas.

	Adobe/Shallow				Clay Loam				Loamy Bottomland			
	Yes (n = 115)		No (n = 261)		Yes (n = 35)		No (n = 341)		Yes (n = 17)		No (n = 359)	
Woody group	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	25.4**[b]	2.5	31.3	1.7	24.4	4.1	30.0	1.5	21.3	5.8	29.9	1.4
Live oak	12.1***	1.5	5.3	0.7	6.9	2.2	7.4	0.7	4.6	2.3	7.5	0.7
Deciduous oaks	4.2***	0.7	10.6	1.1	4.5*	1.7	9.1	0.9	6.9	3.1	8.7	0.8
Deciduous nonoaks	5.8***	1.0	12.1	1.1	19.7***	3.7	9.1	0.8	24.0**	6.9	9.5	0.8
Shrubs	8.5	1.0	8.6	0.7	11.5**	2.0	8.3	0.6	17.3***	3.7	8.2	0.6
Hardwoods (<1.5 m)	8.8	1.0	10.2	0.7	11.2	1.6	9.6	0.6	13.2**	2.4	9.6	0.6
Hardwoods (<3 m)	15.6	1.2	18.4	0.9	20.0	2.3	17.3	0.8	23.1*	3.7	17.3	0.8
Ashe juniper (>3 m)	15.9***	2.1	21.0	1.4	16.4	3.5	19.8	1.2	14.5	4.7	19.7	1.2

Continued.

Woody group	Low Stony Hill Yes (n = 58) $\bar{x}$	SE	Low Stony Hill No (n = 318) $\bar{x}$	SE	Sandy Loam Yes (n = 17) $\bar{x}$	SE	Sandy Loam No (n = 359) $\bar{x}$	SE	Steep Adobe Yes (n = 84) $\bar{x}$	SE	Steep Adobe No (n = 292) $\bar{x}$	SE
Ashe juniper	36.0**	3.6	28.3	1.5	33.7	6.9	29.3	1.4	36.4***	2.8	27.5	1.6
Live oak	5.1*	1.6	7.8	0.7	6.6	2.7	7.4	0.7	3.3***	0.8	8.5	0.8
Deciduous oaks	14.5***	2.6	7.6	0.8	12.0	4.9	8.5	0.8	12.8***	1.9	7.4	0.9
Deciduous nonoaks	6.4	1.3	10.8	1.0	5.3	1.9	10.4	0.9	13.9	2.2	9.1	0.9
Shrubs	8.0	1.4	8.7	0.6	10.6	4.1	8.5	0.6	6.2*	0.8	9.3	0.7
Hardwoods (<1.5 m)	13.7	2.1	9.0	0.6	9.8	2.4	9.7	0.6	7.2	0.8	10.5	0.7
Hardwoods (<3 m)	22.5	2.6	16.6	0.7	18.6	3.7	17.5	0.8	14.7	1.2	18.4	0.9
Ashe juniper (>3 m)	27.3***	3.2	18.0	1.2	22.1	6.4	19.4	1.2	22.9***	2.2	18.5	1.4

Continued.

Woody group	Stony Clay Loam Yes (n = 20) $\bar{x}$	SE	Stony Clay Loam No (n = 356) $\bar{x}$	SE	Other[a] Yes (n = 30) $\bar{x}$	SE	Other[a] No (n = 346) $\bar{x}$	SE	Total (n = 376) $\bar{x}$	SE
Ashe juniper	33.5	6.9	29.3	1.4	18.8***	4.5	30.4	1.4	29.5	1.4
Live oak	10.0	3.4	7.2	0.7	5.9*	2.4	7.5	0.7	7.4	0.7
Deciduous oaks	4.2**	2.1	8.9	0.8	9.6	4.1	8.6	0.8	8.6	0.8
Deciduous nonoaks	5.4	1.9	10.4	0.9	10.6	2.4	10.1	0.9	10.1	0.8
Shrubs	9.7	2.9	8.5	0.6	6.8	2.1	8.8	0.6	8.6	0.6
Hardwoods (<1.5 m)	9.3	2.9	9.8	0.6	9.7	2.2	9.7	0.6	9.7	0.6
Hardwoods (<3 m)	17.1	3.5	17.6	0.8	17.1	2.9	17.6	0.8	17.5	0.8
Ashe juniper (>3 m)	21.9	5.8	19.3	1.2	11.5**	3.5	20.2	1.2	19.5	1.2

[a] Category consists of 10 ecological sites which individually comprised <5% of sites surveyed.
[b] Significant at *$P \leq 0.10$, **$P \leq 0.05$, or ***$P \leq 0.01$ when comparing a specific ecological site category versus all other sites combined (Mann-Whitney tests).

APPENDIX H

Mean density (trees/ha) by woody plant group composition for selected ecological sites in the Leon River Watershed, Texas.

	Adobe/Shallow				Clay Loam				Loamy Bottomland			
	Yes (*n* = 115)		No (*n* = 261)		Yes (*n* = 35)		No (*n* = 341)		Yes (*n* = 17)		No (*n* = 359)	
Woody group[a]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	167.7**[c]	26.1	211.6	17.4	131.9	32.4	205.0	15.6	138.6	54.4	201.0	15.0
Ashe juniper (dbh ≥13 cm)	68.9***	13.4	100.5	10.0	70.9	18.7	92.9	8.7	58.0	24.8	92.4	8.4
Live oak	91.1***	15.8	42.8	6.5	49.1	12.4	58.4	7.3	39.3	15.6	58.4	7.0
Deciduous oaks	31.6**	9.0	60.4	8.8	11.8**	4.5	55.6	7.3	16.9	7.3	53.2	7.0
Deciduous nonoaks	34.9**	6.5	69.3	7.6	126.4***	25.4	51.8	5.6	196.6***	55.4	52.2	5.1
Shrubs	8.6**	3.5	13.8	3.0	26.4	15.8	10.7	2.0	16.9	9.1	12.0	2.4

Continued.

Woody group	Low Stony Hill				Sandy Loam				Steep Adobe			
	Yes (n = 58)		No (n = 318)		Yes (n = 17)		No (n = 359)		Yes (n = 84)		No (n = 292)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	257.9	41.5	187.3	15.3	260.3	65.5	195.2	14.9	232.7***	31.2	188.3	16.4
Ashe juniper (dbh ≥13 cm)	132.3*	25.6	83.3	8.3	127.3*	33.7	89.1	8.3	105.3*	18.7	86.7	9.0
Live oak	41.2**	18.4	60.6	7.2	80.5	31.7	56.5	6.8	21.2***	6.7	68.0	8.3
Deciduous oaks	71.9**	14.6	47.8	7.5	95.5	57.3	49.5	6.5	84.9***	18.9	42.0	6.6
Deciduous nonoaks	31.3	7.3	63.8	6.5	54.3	21.5	59.0	5.9	61.8	11.7	57.9	6.5
Shrubs	6.0	2.0	13.3	2.7	37.4	18.4	11.0	2.3	7.6	2.6	13.5	2.9

Continued.

Woody group	Stony Clay Loam				Other[b]				Total	
	Yes (n = 20)		No (n = 356)		Yes (n = 30)		No (n = 346)		(n = 376)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	256.2	76.1	194.9	14.7	140.1*	48.0	203.2	15.2	198.2	14.5
Ashe juniper (dbh≥13cm)	132.1	44.4	88.5	8.2	47.7**	20.6	94.6	8.6	90.8	8.1
Live oak	93.9**	32.9	55.5	6.8	45.6	20.7	58.6	7.1	57.6	6.7
Deciduous oaks	25.5	13.2	53.0	7.0	54.1	30.6	51.3	6.8	51.6	6.7
Deciduous nonoaks	17.5	5.9	61.1	6.0	67.9	23.2	58.0	5.8	58.8	5.7
Shrubs	9.5	5.2	12.3	2.4	19.1	10.3	11.6	2.4	12.2	2.3

[a] ≥10 cm dbh except where noted.
[b] Category consists of 10 ecological sites which individually comprised <5% of sites surveyed.
[c] Significant at *$P \leq 0.10$, **$P \leq 0.05$, or ***$P \leq 0.01$ when comparing a specific ecological site category versus all other sites combined (Mann-Whitney tests).

APPENDIX I

Mean % ground cover class by ecological sites, from 376 survey sites in the Leon River watershed, Texas.

	Adobe/Shallow				Clay Loam				Loamy Bottomland			
	Yes (*n* = 115)		No (*n* =261)		Yes (*n* = 35)		No (*n* = 341)		Yes (*n* =17)		No (*n* = 359)	
Ground cover	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	14.7***[b]	0.9	9.0	0.6	7.7	1.9	11.1	0.6	6.1**	0.9	11.0	0.6
Rock	7.1	1.6	10.1	0.6	7.5	2.6	9.3	0.6	6.1**	1.5	9.3	0.6
Litter	43.8	3.5	46.4	1.2	40.1	6.2	46.1	1.2	43.8	2.7	45.7	1.3
Forbs	9.5*	1.2	8.0	0.5	8.3	2.3	8.5	0.4	10.7	1.0	8.4	0.5
Grass	24.6	3.7	25.4	1.0	33.8**	5.6	24.3	1.0	30.0	2.8	24.9	1.0

Continued.

Ground cover	Low Stony Hill				Sandy Loam				Steep Adobe			
	Yes (n = 58)		No (n = 318)		Yes (n = 17)		No (n = 359)		Yes (n = 84)		No (n = 292)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	7.0***	2.2	11.4	0.6	10.6	1.0	10.8	0.6	9.1*	2.5	11.2	0.5
Rock	9.9*	1.9	9.0	0.6	4.8***	1.5	9.4	0.6	15.2***	1.6	7.4	0.6
Litter	49.6	4.6	44.8	1.2	45.2	2.2	45.6	1.3	49.1*	5.3	44.5	1.2
Forbs	7.1*	1.9	8.7	0.4	7.3	0.8	8.5	0.5	7.5	1.3	8.8	0.4
Grass	25.3	3.8	25.1	1.0	27.8	1.5	25.0	1.2	17.8***	5.5	27.3	1.0

Continued.

Ground cover	Stony Clay Loam				Other[a]				Total	
	Yes (*n* = 20)		No (*n* = 356)		Yes (*n* = 30)		No (*n* = 346)		(*n* = 376)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	12.9	1.1	10.6	0.6	12.3	2.5	10.6	0.5	10.8	0.5
Rock	6.9	0.8	9.3	0.8	6.4*	3.6	9.4	0.6	9.1	0.6
Litter	41.9	2.1	45.8	1.4	44.6	6.6	45.7	1.2	45.6	1.2
Forbs	7.2	0.8	8.5	0.5	10.2	1.7	8.3	0.4	8.5	0.4
Grass	31.8	1.5	24.8	1.3	28.6	5.1	24.8	1.0	25.1	1.0

[a] Category consists of 10 ecological sites which individually comprised <5% of sites surveyed.
[b] Significant at **P* ≤ 0.10, ***P* ≤ 0.05, or ****P* ≤ 0.01 when comparing a specific ecological site category versus all other sites (Mann-Whitney tests).

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